# Earth Station Symposium

Scientific Atlanta

Scientific
Atlanta

3845 Pleasantdale Road, Atlanta, Georgia 30340 Telephone 404 449-2000 TWX 810-766-4912 Telex 054-2898

December 13, 1978

Mr. R.B. Cooper, Jr.
Editor-in-Chief
CATJ
4209 N.W. 23rd Street
Suite 106
Oklahoma City, Oklahoma 73107

Dear Mr. Cooper:

We have just completed our fourth successful satellite communications symposium with 300 people in attendance. We had Broadcast and Cable TV marketing personnel and engineers from 34 states, France, Sweden, Germany, Puerto Rico, and the Canal Zone.

Enclosed is the earth station symposium book featuring the technical papers presented during the conference.

We are anxious for you to consider publishing these in your magazine. Once you decide, let me know and I will round up the appropriate photographs and artwork to support the articles.

Thank you for your consideration.

Sincerely,

JF

John Feight
Manager of
Marketing Communications

JF/ls

Enclosure

# Index

# THE OUTLOOK FOR SMALL TO MEDIUM EARTH STATIONS AND ASSOCIATED EQUIPMENT

Howard L. Crispin
Senior Vice President
Communications Group

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## THE OUTLOOK FOR SMALL TO MEDIUM EARTH STATIONS AND ASSOCIATED EQUIPMENT

From its birth in 1962 Satellite Communications can, in many ways, be likened to the growth of a child. In its early years it was almost entirely dominated by its parent, technology. Over the years it has grown and has been influenced by outside forces such as political, economic, and social pressures. Today, technology, while still a major factor in shaping its future adult personality, is only one of many factors.

This is not an unusual scenario in the development of a new industry. It does, however, present some very unique problems (read; opportunities) to those either directly or indirectly involved. Technological advances are rapid and accelerating. The need for communications is basic and apparently insatiable in humans.

As launch vehicle and satellite technology have advanced to allow larger, expanded capability satellites to be placed in orbit, the size and cost of earth terminals has decreased and economics of scale have reduced both the space and earth costs of satellite communications.

Domestically, the Domestic Satellite, "Open skies", ruling of December 1972 brought to bear the tremendous forces of competition and a step function in the growth of satellite communications was initiated.

As the size and cost of earth terminals was reduced and user owned terminals became practicable, satellite communication became a viable alternative to classic communications systems.

Its advantages of distance insensitivity, point-to-multipoint capability, and improved quality over long distances are unique and many developing countries have seen that satellite communications is the only solution where alternative communications infrastructures did not exist and could only be provided over a long period of time and at excessive cost.

During the early years of satellite communications the use of the medium and the configuration of the equipment was dictated by technology.

Space technology influenced the size of the launch vehicle and subsequently satellite size which in turn affected the amount of communications equipment, power equipment, and station keeping capability of the satellite.

Due to the transmitted power limitations of the satellite, earth stations were very large and very expensive and only large carriers or countries could offer satellite communications services. As technology advanced satellites became larger, more powerful and more versatile. This has allowed the size and cost of earth stations to be reduced to the point where many new services are practical. Earth stations with antennas as small as six feet in diameter are being seriously considered, compared to ninety foot reflectors ten to twelve years ago.

This evolution has now allowed an entrepreneural influence in the design and implementation of new satellite communications services. Business decisions, within the boundries of regulatory constraints, are becoming increasingly important in definition and speed of development of the industry.

As business entities have stepped forward and shown the ease, speed, and economics of using satellite communications, other forces are being increasingly felt. Social forces to utilize this technology for health, education, and religion. Political and economic forces to either further open or further constrain the use of satellite communications.

In many ways, INTELSAT is the "big brother" of all satellite communications.

"Early Bird" (INTELSAT I) satellite provided the world's first commercial satellite communications when it was placed in service during June 1965 and for the first time made live transoceanic TV possible. In just 13 years the INTELSAT system has taken on truly global proportions, handling today more than two thirds of all transoceanic traffic.

The International Telecommunications Satellite Organization (INTELSAT) originated as an international joint venture in August 1964, signed as an agreement by representatives of 11 countries. In January 1978, 101 member nations participated, alphabetically spread from Afghanistan to Zambia. The United States is represented by the Communication Satellite Corporation (COMSAT) which now has 7 U.S. earth stations and about 25% investment share in INTELSAT.

Around the globe at December 1977, over 200 earth stations were in operation (142 furnishing international service, 62 furnishing domestic service) and 25 more stations are planned for 1978.

The international stations tend to be large and complex. The Standard "A" version uses antennas in the range 97 - 105 feet diameter. The smaller "B" stations also for international service have antennas typically 33 - 39 feet diameter. Those in dedicated domestic service are about the same size as the "B" station antenna. You don't see any of the small 15 foot variety antennas operating with INTELSAT yet except in experimental or special use applications.

Current operating satellites are the INTELSAT IV and IVA series. The IV, placed in service between 1971 and 1975 have a capacity of 4000 telephony circuits plus 2 TV channels, rendered through 12 transponders each with 36 MHz bandwidth. INTELSAT IV introduced the spot beam concept, a concentration of satellite communications capability onto small areas. The newer IVA series have 6,000 circuit capacity plus 2 TV channels and are in service over the Atlantic. Another is planned for service over the Indian Ocean this year. The IVA satellite has 20 transponders and employs a design permitting the simultaneous use (called "reuse") of the same frequencies through directional antennas for both reception and transmission.

INTELSAT V, planned for launch in 1979, is already under contract. It will provide 12,000 circuits plus two TV channels. The capacity is achieved by the use of 14/11 GHz frequency bands, in addition to the 6/4 GHz bands. The 6/4 GHz frequencies are used four times and the 14/11 GHz frequencies are used twice.

It is easy to see that INTELSAT got a head start on other satellite networks and maintains a technical leadership role. Their initial goal and a current major one is to handle international message and TV circuits. They have established and continue to promulgate well defined technical standards of operation, keeping in mind that service through the INTELSAT satellite is only one link in the overall transmission path between end users. So the satellite transmission is expected to preserve good quality, suitable for additional transmission processes.

INTELSAT, as you may guess, is particularly sensitive to the potential problem of interference between adjacent satellites. After all, two interfering satellites could belong to two different countries who are nevertheless members of INTELSAT and meet together frequently as representatives of their governing board.

Consider the situation of some U.S. domestic service where one satellite link goes all the way from originator to consumer and it is easy to see that smaller antennas and less sophistication which may be sufficient for U.S. domestic service would hardly be sufficient for international traffic.

INTELSAT does provide "domestic" service capabilities outside the U.S.A. Stations are operating in several countries: Algeria, Brazil, Chile, Nigeria, Norway, Saudi Arabia, Sudan, Malaysia. Others are planned. For this dedicated service, leased transponder capacity is available to the countries from INTELSAT where no other satellite may be available to serve the country. INTELSAT has and plans to have additional satellite capacity available. When use of the leased capacity service is made, antenna size at the earth station is typically in the 10-11 meter range. Since the leased transponders typically operate through the satellites global beam, satellite EIRP almost precludes use of smaller size antennas. But remember, it is possible that service in the future could be handled by the satellite "spot beam" with significantly increased EIRP. Perhaps concurrently with that development, INTELSAT may augment their preferred method of handling TV associated audio to be more analoguous to the conventional U.S. subcarrier method. Those ways and others then could serve to reduce the station size and price of domestic service through INTELSAT.

Simultaneously with the growth of INTELSAT, countries overseas in some cases have purchased and launched their own dedicated satellites independently of INTELSAT. The Canadians have ANIK, the Indonesians have PALAPA and others are in the works. Those have in common with U.S.A. domestic satellites the general feature of higher EIRP. And from that feature results the possibility of having vast quantities of relatively small and cheap stations functioning to furnish country wide telephone and TV distribution. Indonesia alone has 3,000 "villages" needing such services.

Satellite and cable communications is an exciting story, a classic example of the private enterprise system working to produce in a few short years what on paper would look like long, rocky years of planning, negotiating and weighing short-term indicators. Manufacturers, programmers, and system operators took bold, innovative steps and brought strength and excitement to a sometimes shaky industry.

The story begins in late 1972, when Hub Schlafly, who as then Senior Vice President of Engineering for TelePrompTer Corporation, became interested in pursuing the feasibility of communications via satellite for cable. The Canadian satellite, ANIK, was in a stationary geosynchronous orbit off to the southeast and could be interrogated by a receive-only earth station in most parts of the U.S. for feasibility purposes.

Scientific-Atlanta became a partner in this interest and produced a 8-meter transportable earth station. It was delivered to TelePrompTer in 1973, at the National Cable Television Association Convention in Anaheim. The unit was set up in the parking lot of the convention center and pointed at ANIK. This demonstrated the feasibility of satellite communications for cable in very graphic terms to the cable industry. Most of the major operators at the convention felt the earth station for CATV was ahead of its time since there was no U.S. domestic satellite system in operation. TelePrompTer, over the next several months, demonstrated the unit at 28 of their system locations.

In a parallel vein, Western Union was dedicated to launching Westar in early 1974, thereby establishing a U.S. DOMSAT communication network. At this point representatives of Scientific-Atlanta met with interested parties from Home Box Office, major MSO representatives and domestic satellite carriers. The point was made that the network existed and could therefore be utilized.

The next major event occurred at the National Cable Television Association Convention in New Orleans in 1975, when HBO announced their intention to put programming on either the Western Union bird (already operating) or the panned RCA SATCOM I satellite.

At the same meeting in New Orleans, UA-Columbia announced their agreement with Home Box Office to receive satellite pictures in several of their system locations throughout the U.S. and these receive systems were ultimately purchased from Scientific-Atlanta. HBO signed an agreement with RCA, who in turn leased space with Western Union for the initial programming on September 30, 1975, and it was stated that RCA would transfer to their own satellite, SATCOM I, as soon as it was operational in late 1975. In the spring of 1976, cable programming was put on RCA's newly launched SATCOM II.

The FCC at that time only allowed antennas which were greater than 9-meters in diameter. The first two installations were Scientific-Atlanta's 8003 10-Meter Receive-Only Earth Stations and they were installed in Ft. Pierce, Florida for UA-Columbia and Jackson, Mississippi for ATC. The results of these operations were carefully measured and success was evident early, therefore inspiring other operators to install 10-meter earth stations in most key systems. By December of 1976, there were approximately 130 10-meter stations in operation receiving HBO.

On December 7, 1976, the Federal Communications Commission issued a declaratory ruling to allow the use of earth station antennas smaller than 9-meters in diameter. The Commission's decision was based upon sound evaluations of stated objectives of potential users as well as the state-of-the-art of equipment suggested for use to meet those objectives.

Almost simultaneously, the FCC granted a license to Southern Satellite, Inc., to provide a common carrier service of WTCG, Channel 17, Atlanta, for reception by cable television operators. This grant marked the introduction of the second program source via satellite.

Consequently a new era of satellite for cable was initiated wherein cable systems, large and small, could seriously consider and economically justify the employment of satellite program services as an integral part of their commitment to entertainment to the home.

Immediately after the December events, several manufacturers, including Scientific-Atlanta, announced their product support of the small aperture earth station market. Applications for authority to own and operate earth stations less than 9-meters in diameter began rolling into the FCC, and the second phase of satellite for cable was underway.

Since December 1976, over 700 small aperture stations licenses have been granted and the FCC is currently processing approximately 60 applications per month. As of September 15, 1978, a total of 386 earth stations have been installed by Scientific-Atlanta.

In addition to HBO and WTCG, Channel 17, the cable operator today can select from a number of satellite program alternatives including other pay packages. These include Showtime and Fanfare, religious programming presented by CBN, PTL, and Trinity Broadcasting, the Spanish International Network and special events from Madison Square Garden.

The future indeed looks promising. It appears that within 2-3 years the vast majority of CATV systems will have their own receive-only earth stations. Industry estimates are that there will be approximately 4,000 cable systems in 1980. It seems reasonable to expect about 3,000 CATV earth stations by that time.

In addition to current types of video services, at least two "electronic newspaper" services are in the planning stages using a slow-scan video format. The service will provide TV photographs with an accompanying audio story or by-line. The technical format will be one or two subcarriers transmitted along with a transponder's primary video and audio carriers.

Another area of growth in video applications of satellite communications is competing services on competing satellites. Currently in planning and testing stages is a four video channel service on the Western Union satellite. In addition to multi-channel earth stations, we may be seeing multi-earth station receive sites as video services on different satellites become attractive on a cost-versus-revenue basis for the CATV operator. Perhaps this borders on "blue sky" predictions; but who would have forecasted in 1975, that there would be over 300 CATV earth stations by the beginning of 1978?

Cable and satellites for cable TV have come a long way in a short time span. Operators are much more educated about video satellite transmission and the benefits of satellite communications for cable. As a network, satellites for cable represent the largest receiving satellite communications system in the world.

The use of satellites for video and audio program distribution is exploding. Will the broadcast industry turn to satellite for program distribution as the CATV industry already has done? Will this happen soon? Will it lead to new opportunities in programming, and will it eventually change the structure of the industry?

It is still too early to be sure, but if one were to hazard an educated guess, the answers to these questions would be, respectively, it probably will, it may happen soon, it will surely offer new opportunities, and it just might change some things radically — networking for example. These answers are based partly on what has been happening in the CATV area and partly on what broadcasters are already doing.

So far, the broadcast industry does not have this general satellite networking capability. About twenty commercial television stations have applied for earth station construction permits — and only twelve of these are in actual operation. However, the interest is high among broadcasters and many things are now happening which indicate this situation will change, and perhaps very rapidly.

Although broadcasters do not have many earth stations, there is already a large amount of broadcast-type programming on the satellites. They include "specialty" broadcast services, custom video services, and various network transmissions.

As yet, there are not full-service broadcast networks distributing their programs by satellite. But there are several organizations distributing "specialized" programming to a selected group of stations either entirely, or primarily, by satellite. They include the Independent Television News Association (news stories), Spanish International Network (Spanish language programs) and Public Broadcasting System. All of them use the same basic technology (i.e., point-to-multipoint transmission). But they differ in motivation and approach, and the differences illustrate the wide range of possibilities in satellite distribution of programs.

Independent Television News Association was the first broadcast organization to use satellite distribution on a regular day-to-day basis. ITNA is a group of independent TV stations, who pool their newsgathering resources to make up a national news service. News stories are fed by the ITNA stations to a New York news center. There the stories are assembled, edited, and sent by satellite to all the member stations. An average of 22 news stories are transmitted during a one-hour period each day. Member stations tape these and select from them in making up their own news shows. They buy satellite time on a contract basis from the Robert Wold Company.

Spanish International Network was the first broadcast network to distribute its programs by satellite. At present, eight SIN affiliated TV stations receive SIN programming by satellite. Two of them (WLTV Miami and KWEX-TV San Antonio) have their own earth stations - a third, KMEX-TV Los Angeles, is installing one. The others receive SIN programs via Western Union earth stations. Eventually, SIN says, all eight SIN stations will have their own earth stations. Much of their programming is live from Univision, the international Spanish TV network. This originates in the studios of Televisa, Mexico's national network. It is carried by microwave line to San Antonio, where it is sent up to the satellite by KWEX-TV's own transmit earth station.

Public Broadcasting Service is well along with its program to go entirely to satellite distribution. It is installing facilities, which, when completed in early 1979, will include the main transmit/receive earth station near Washington, four regional transmit/receive earth stations and receive-only earth stations at all TV stations carrying PBS programs (expected to be 162). The first of these earth stations are being tested now.

The PBS transmissions will be via Westar — starting with three full time channels, with a fourth to be added later. The economies are such that (after the earth stations are paid for) the annual cost of the four channels will be less than the cost of one terrestrial channel.

Three religious organizations — The Christian Broadcasting Network (CBN), the PTL Television Network and Trinity Broadcasting Network (TBN) are major suppliers of religious/family programming by satellite. Typical programming includes religious talk shows, women's programs, teaching shows, musical variety programs, and youth-oriented shows. Each organization already has its own transmitting and receiving earth station located near extensive studio production facilities, and all three have extensive plans for setting up broadcast TV networks via satellite.

Custom networks formed to distribute special programming by satellite are common today. The "packagers", particularly the Robert Wold Company and Hughes Television Network, specialize in putting together ad hoc networks for sports events and for other specials such as Nixon-Frost interviews, Live from Lincoln Center, The Nashville Scene, and many more. By contracting with RCA Americom and Western Union to take a large number of

hours per year, both Wold and Hughes Television can buy satellite time at very favorable rates. Each company uses some of this time for their own custom networks and sell the rest to small users. The latter benefit from this arrangement since they can usually buy a few hours per month cheaper from Wold or Hughes than from the common carriers.

The three major television networks are not presently using satellites for program distribution — and, apparently, do not have any near time plans to do so. But they are using satellite circuits in a big way for a long list of special purposes. These include the so-called "occasional" circuits for sports feeds, the special circuits for feeding west coast programs to New York — and a number of services for Alaska.

ABC, CBS, NBC "occasional" use of specially arranged satellite links has grown from a trickle to an avalanche. All three networks are using satellite circuits to bring news pickups and sporting events from the field back to network centers — and in some cases to feed these to regional distribution centers. The satellite links are often cheaper, and, in some cases, are the only circuits available (e.g., on heavy sports weekends).

NBC Television Network has a contract with RCA Americom for use of transponder circuit between Los Angeles and New York. Mostly this is used for bringing west coast produced shows (that are aired live) to the New York network distribution center. These include the Tonight Show, news pickups, and some specials. Actual usage is reported to be averaging about seven hours a day at present.

Alaskan services is actually a group of services. At the present time, RCA Americom transmits selected programs of the three networks to TV stations in Anchorage, Fairbanks, and other cities on an as-ordered basis. It also has a complex setup for feeding Alaskan "bush station" receivers. To do this, selected TV station programs — independent as well as affiliates — are transmitted to Anchorage, using unique two channel per transponder system — which requires a special type of receiver. These signals are taped for later satellite retransmission to the "bush" stations. At the "bush" stations the signals are rebroadcast by a low power television transmitter.

In addition to video programming, there is already some — and shortly will be a lot more — radio programming carried by satellite. At the present time, all the radio networks, as well as both AP and UPI audio news, are using satellite circuits between the east and west coasts. These are basically "trunking" circuits — the kind of usage that was envisioned when satellites first came on the scene. What is more interesting is the emerging use of satellites as a method of distributing radio programs to the station. Both Mutual Broadcasting System and National Public Radio are well along with elaborate plans to do this.

The really interesting thing about this long list of present and planned satellite programs is the trend that is developing. A lot of the satellite use until now has been for point-to-point transmission (the network remotes, the Hughes and Wold ad hoc circuits, etc.). But there is a strong and growing use for multipoint distribution (ITNA, SIN, CBN). And as other planned services are implemented, this trend will become even more evident. Before very long, multipoint distribution will be the predominate usage.

Most of the multipoint distribution, so far, has been of specialized programming. And it has been addressed to selected stations (e.g., ITNA to its member stations, SIN to its owned stations, etc.). Thus, most of the broadcaster owned earth stations are presently being used to pick up just one type of programming. This will probably change. As more and more programs become available from the satellite, TV stations will no doubt find that they want to pick up programs from several sources. Already KSTW-TV in Seattle is using its earth station to pick up CBN's 700 Club, as well as the ITNA news, from the satellite.

It will be surprising if this does not become a pattern — especially for independent stations. Once they have installed an earth station, they can pick and choose among the programs available via satellite. They can air these programs live or tape them for later use. They won't be limited by line availability or timing. And they will be in a position to join ad hoc networks, or take one-shot specials.

The possibilities of satellite distribution will surely not be lost on the commercial broadcasters. Exactly how they will use this new tool remains to be seen — it will probably have to evolve from experimentation. But one thing seems certain — television and radio station executives will have more choice in programming.

Lets consider next two important examples of small aperture earth stations.
One for Digital Transmissions, and
One for Marine Communications.

The Marisat system is in commercial operation providing high quality marine telephone and telex service using a 4 foot diameter antenna.

The Marisat system is unique in that it is used aboard ships and is as simple to operate as a telephone or telex machine, not requiring a skilled operator. Marisat provides voice and telex service, the quality of which is equal to or better than terrestrial circuits. Since the circuit through the satellite is virtually unaffected by weather or ionosphere conditions, contact with an equipped ship by any telephone or telex connected to the international system can be made at any time.

This is contrasted with traditional MF/HF radio telegraphy where the average time to get a one way message delivered in six hours, and involves highly trained radio operators at the coast stations and aboard the ship.

The four foot diameter Marisat ship antenna must be continually aimed at the satellite despite the ship's rolling, pitching, turning, and changing geographic location. This requires a complex four axis antenna that is automatically stabilized by a servo system using rate and level sensors and the ship's gyrocompass. To compensate for a change in location, which of course changes the azimuth and elevation angles to the satellite, a step tracking system is included to continually seek the maximum signal. The ship terminal is almost entirely automatic and includes stabilization and repointing of the antenna as well as tuning of the transmitter and receiver.

The Marisat satellite system has truly revolutionized communications between ship and shore and is one of the major advances in ocean shipping during the past seventy five years.

For the case of digital data transmission by satellite, we have experienced the emergence of a market for small aperture earth stations to provide data links via satellite between the facilities of general business and industry. These earth stations, using small antennas in the 5 meter category, are

designed to be located on or near the end users premise. In addition to the antenna, a typical terminal contains GaAs FET low noise amplifiers, high power amplifiers (100-500 watt) and 56K bit digital modems using QPSK and BPSK techniques. The active components can be single strand, fully redundant, or could utilize a fail-soft technique to provide the necessary system availability commensurate with the end users needs. The modems can be single capacity or they can be multiplexed to provide a greater data capacity for the link or modems with higher data rates, such as 224K bit can be utilized.

The present principal function of this type of earth station is to connect two offices together for the exchange of information — formatted as digital data. Such data may be computer-to-computer dialogue, entry to, computation and retrieval from a central computer, printed information, digitized voice or facsimile. Such circuits may be switched, dedicated, or on demand.

While data rates beyond 5 MBS are required in some cases, most applications appear to be served by 56 KBS rates. Using available techniques for forward error correction which permit bit error rates of less than one error in ten million bits, antennas in the 15 feet to 30 feet range and transmitters well under 100 watts power become practicable. This results in a low cost transmit earth station, compared with a video earth station that requires a 33 foot antenna and a 3 KW transmitter. Further, the antenna is small enough so that it can be located on the users premises thus eliminating local links. In many cases, the antenna may be installed on the roof of the users building.

The availability of the products and the technology exists and awaits the direction of the marketplace. At present, American Satellite Corporation is providing this service and has reported contracts with Sperry and Western Bank. RCA American and Western Union are also beginning to pursue this market.

The interest and emphasis has resulted in FCC approval on this type service, and this market has enormous potential in general business — banks, factories, airlines, etc.

If we were to assume that one-half of the Fortune 500 companies has 3 facilities each that needed this service,we are talking about 45-50 million just in ground station hardware (60K each). This may be unrealistic since probably most of the Fortune 500 companies have more than 3 facilities to link via satellite. Of course, economics will be the final determining factor in any market and it must be assumed the analysis to date has indicated the practicality of using satellite for this service even at today's prices.

AT&T could impact the market by lowering the cost of their present service; however, it is more likely that AT&T will join the ranks of those providing the service via satellite.

In any case, we expect that data systems will enjoy one of the highest growth rates in satellite systems over the next five to ten years.

Other opportunities are available in areas associated with satellite communications. These opportunities are to develop, market, and sell standard products in the areas of, monitor and control, signal processing, signal distribution signal conditioning and an area that will probably see increasing demand, signal security.

Monitor and control includes all the necessary devices such as equipment protection, switches, status and control panels, remote control circuits, and the like. Scientific-Atlanta is already providing units such as baseband protection switches, video protection switches, HPA protection switches, LNA protection switches, and others. The purpose of such devices are to sample and sense the "life" status of the on-line units and in the event of a failure, to quickly switch a backup unit on-line.

Status and central units take "on-line" status information as well as "life" information and either display and/or passes it along via a remote control and status panel to the ultimate user.

Signal processing equipments are those that are not necessarily a part of the Satcom terminal but are closely associated with it. The equipment includes voice and data multiplex, interface level and signaling adapters, and other types of units.

Multiplex equipments are needed in various varieties. They include frequency division multiplex and time division multiplex each designed to operate with, frequency modulation, phase shift keying, and others. This equipment processes the signals into a configuration suitable for transmission over the satellite. Various other equipment is available and/or needed for level and signaling interface adaptors between the local exchanges, the microwave relays, and the other medium of distribution.

Signal distribution includes all the equipment necessary to take the signals between the earth station and the ultimate user. These equipments include cable and cable devices; microwave equipment, which includes a multitude of equipments such as transmitters, receivers, repeaters, tower antennas, and the like; and fiber optics or light pipes in which the communication information is converted to a light beam and then is transmitted via a very small fiber to the user and reconverted to electronic impulses. This method is becoming more attractive for relatively short distances as the cost becomes lower. Broadcast transmitters are also utilized to "rebroadcast" both audio and video signals after being transmitted through the satellite maybe as far away as Hawaii to New York. This method of distribution may become extremely popular depending upon decisions at the Federal Communications Commission in the very near future.

Signal conditioning equipment for the earth station is also required. This equipment is required to compensate for non-linearities, which unless compensated for, degrade performance and essentially create high cost in equipment and life cycle.

A new area that is just over the horizon is communication security. Prior to satellite communications and the customer premise terminal, most communication was accomplished with the telephone. With the customer premise terminal, an astute technician with no scruples would receive and monitor competitors or potential competitors communication, without being in the vicinity of the competitor and at very little cost, since the satellite signal is available nationwide.

In order to minimize corporate espionage, voice and data security units may be required.

These opportunities mentioned are just a few of the areas where tremendous opportunity is available to provide products and equipment to satisfy the ever expanding satellite communications field.

# The Growth and Future of Satellite Communications

by

Sidney Topol
Chairman of the Board and President
Scientific-Atlanta, Inc.

# The Growth and Future of Satellite Communications

by

Sidney Topol
Chairman of the Board and President
Scientific-Atlanta, Inc.

The advent of satellite communications has captured the interest and imagination of nearly everyone associated with wide-band communications. The technology necessary for satellite communications has been reduced to practice in international telecommunications, domestic communications and maritime communications systems. Virtually the whole world -- from the busiest urban center to the most remote islands -- can be interconnected by satellite communications networks that are capable of providing economical, reliable transmission of communications signals, including voice, teletype, data and video.

The field of commercial satellite communications is based on the use of geosynchronous satellites. The geosynchronous orbit (Figure 1)

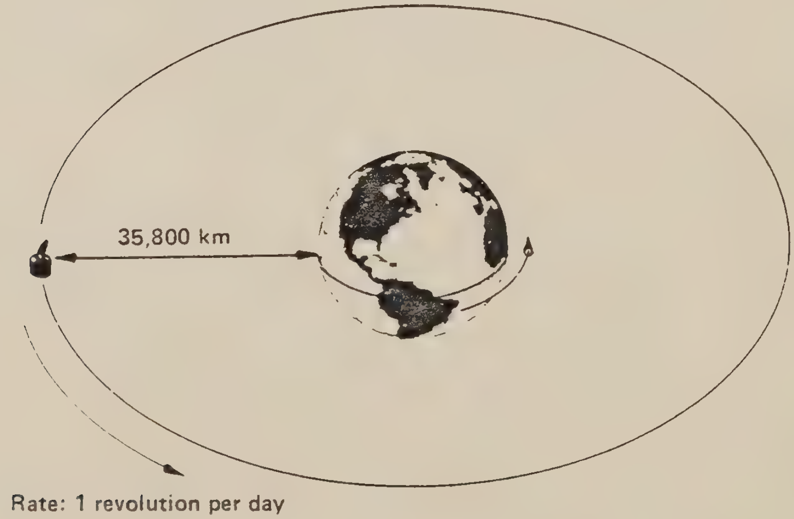



Figure 1. Communications satellite in geosynchronous orbit.

is the circular orbit which lies at a height of about 35,800 (22,250 miles) above the equator. A satellite in this orbit appears fixed in space to an earth station on the ground. This has the obvious advantage of greatly simplifying the earth station configuration, since complex tracking electronics and the associated precision servo-powered drives for the antennas are not required. Except for small regions near the North and South poles, widely separated earth stations can be seen from a single geosynchronous satellite. For example, Prudhoe Bay at the northern end of the Alaskan pipeline and villages much farther north in Canada have television reception and voice communications with the world by satellite.

Satellite communications made possible trans-Atlantic television in 1962 before the first synchronous satellite was launched. Television pictures and the other signals were transmitted between a specially built AT&T station in Andover, Maine and both English and French stations using TELSTAR, a low-altitude, orbiting satellite, which was built and launched at the expense of AT&T. The first launching and use of synchronous satellites came in 1963 when NASA successfully demonstrated television transmission through the SYNCOM II satellite, built by Hughes.

## INTELSAT

Shortly after the launching of TELSTAR and before SYNCOM, Congress passed the Satellite Communications Act of 1962, which authorized the formation of Communications Satellite Corporation (Comsat) as a private company chartered to establish a global commercial satellite communications network in cooperation with other countries. Under Comsat's leadership, the International Telecommunications Satellite Organization (INTELSAT) was formed in August 1964. It was originally comprised of 11 countries, with Comsat representing the U. S. A. INTELSAT has matured rapidly during its 14-year life. Figure 2 shows the current INTELSAT Global Communications System.

Figure 2. INTELSAT Global Communications System. Courtesy COMSAT.

At the end of 1977, 101 member nations participated in INTELSAT, alphabetically spread from Afghanistan to Zambia. Around the globe, 201 antennas were in operation at 163 station sites (147 antennas furnishing international service, and remainder furnishing domestic service), and 25 more stations were planned in 1978. Comsat has a 50% ownership interest in the seven U. S. earth stations* and an investment share of about 25 percent in INTELSAT.

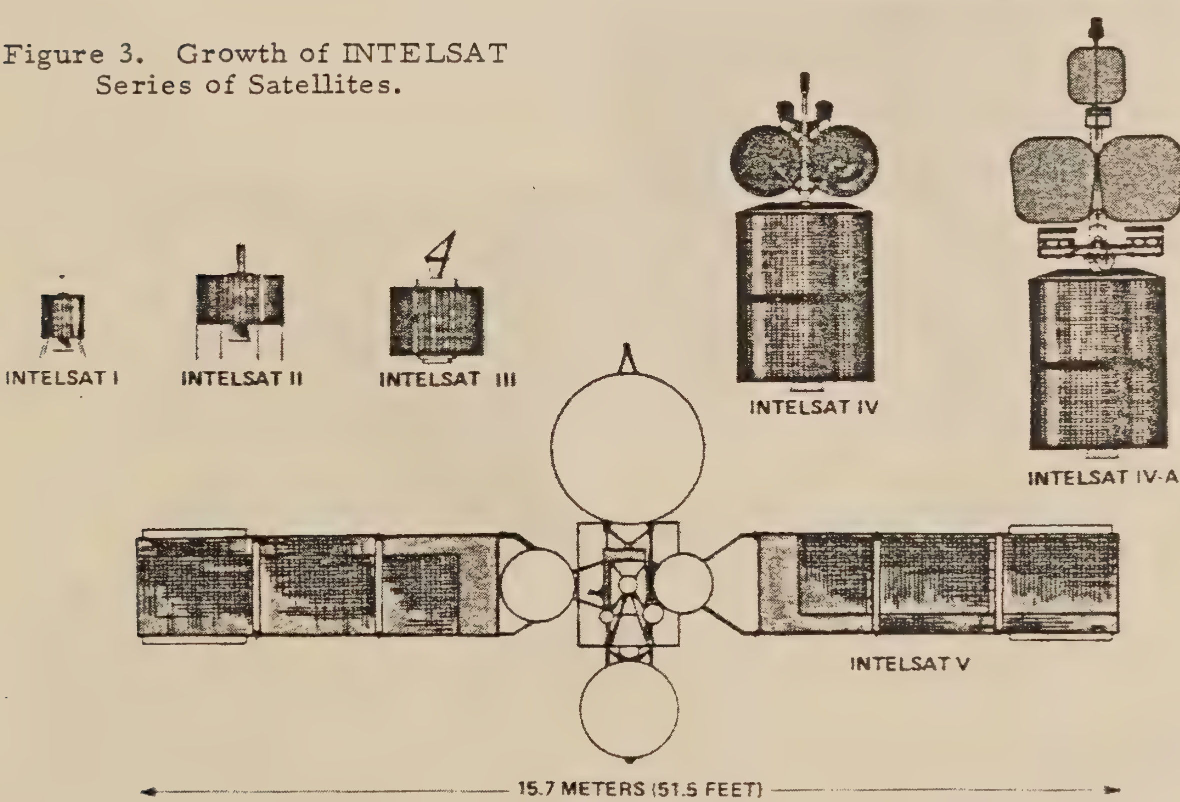
---

*The U. S. earth stations in the INTELSAT network are owned in common by a consortium of United States carriers, including Comsat, AT&T, Hawaiian Telephone Company, All America Cables & Radio, Inc., ITT World Communications Inc., RCA Global Communications, Inc., and Western Union International, Inc.

The INTELSAT Global System and the vast majority of all commercial satellite communications are now in the 6/4-GHz terrestrial common-carrier microwave communications bands. Uplink transmission is at 6 GHz and downlink is at 4 GHz. The available bandwidth is 500 MHz in each band. These bands were chosen because they were available and were consistent with the state of the art and the technical and environmental requirements for wide-band satellite communications.

Tracing the increase in capacity and capabilities of each succeeding generation of INTELSAT satellites provides an idea of the growth of international satellite communications. The complete INTELSAT Series of satellites is shown in Figure 3. INTELSATS I, II, IV and IVA were built

Figure 3. Growth of INTELSAT Series of Satellites.



by Hughes. The INTELSAT III series was built by TRW. INTELSAT V, planned for launch in 1979, is under contract to Ford Aerospace. A conceptual view of INTELSAT V is shown in Figure 4.

INTELSAT I was placed in service in June 1965. It had a capacity of 240 voice-grade circuits or one TV channel (not both simultaneously), and it provided service only between Europe and North America. It did not have multiple-station access capability.

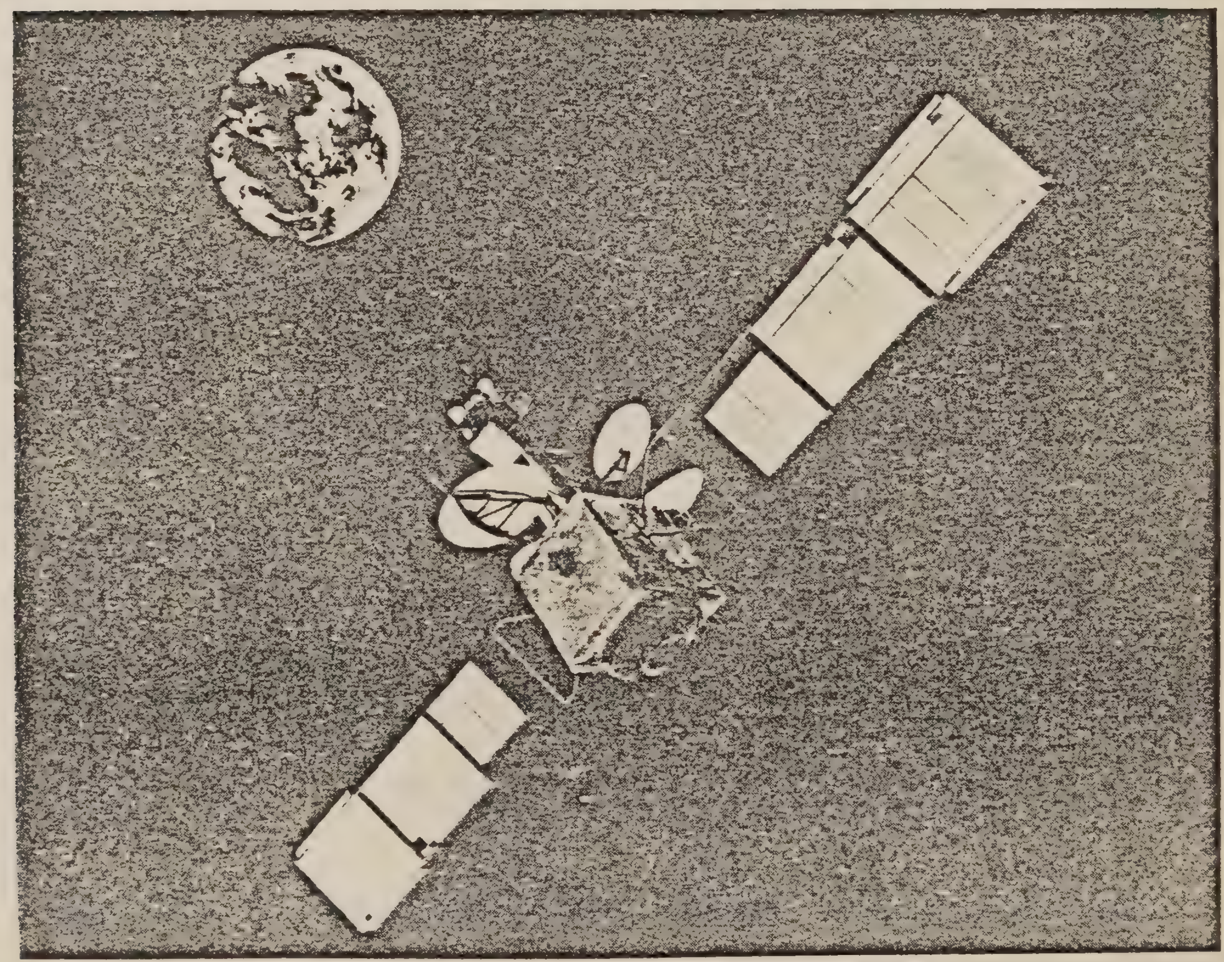


Figure 4. Conceptual view of INTELSAT V in geosynchronous orbit.

INTELSAT II had the same capacity as INTELSAT I, but introduced multipoint access and earth-mode coverage. INTELSAT III had capability for transmitting a number of forms of communications simultaneously. It had a capacity of 1500 circuits or four TV channels. INTELSAT IV has an average capacity of 4000 circuits plus two TV channels, utilizing 12 transponders, with bandwidths of 36 MHz each.

The latest operational series, INTELSAT IVA has an average capacity of 6000 circuits plus two TV channels. It has 20 transponders, each with a 36-MHz bandwidth. INTELSAT V will have an average capacity of about 12,000 circuits plus two TV channels. It has global, spot and zone-coverage beams and has capability for switching transponders between beams for operational flexibility. Its capacity is achieved by use of the 14/11-GHz bands, in addition to the 6/4-GHz bands.

INTELSAT IVA and INTELSAT V are designed to increase their effective use of the spectrum by the technique called "frequency reuse". The directional antennas of INTELSAT IVA permit it to use the same frequencies twice by providing space discrimination. In addition, INTELSAT V will transmit and receive simultaneously on orthogonal polarizations to achieve a nominal reuse factor of four in the 6/4 GHz band. The reuse factor of INTELSAT V drops back to two in the 14/11 GHz band, where reuse of orthogonal polarizations is not employed.

Most of the INTELSAT earth stations use large antennas (typically 30 meters in diameter) and extensive ground communications equipment to funnel large volumes of traffic into and out of the member countries. The antennas for this service are called Standard "A" antennas.

INTELSAT has now approved the use of smaller earth stations with the INTELSAT IV and IVA satellites. This has contributed greatly to the recent worldwide growth of satellite communications. These stations may use antennas with diameters as small as 11-meters. Known as Standard "B" earth stations, their greatly reduced size and cost allow many countries to belong to INTELSAT which otherwise could not afford satellite communications.

Domestic and Regional Satellite Systems

Figure 5 shows the current geosynchronous communications satellites serving North America. These 10 satellites will soon be joined by several planned additional satellites. They will then represent a combined capability of well over 200 transponders, with an average bandwidth of greater than 35 MHz each. Of the 10 communications satellites now serving North America, seven serve the United States.

Canada was the first country to establish a domestic synchronous-satellite communications system. Canada's population is spread out over a tremendously large area, from ocean to ocean and from the provinces in the south to the territories, which extend above the Arctic Circle. It is not practical to interconnect the whole country with a terrestrial-relay communications system. Satellite communications provides a natural means of circumventing this problem. Consequently, Canada established Telesat Canada in 1969 to install and operate a satellite communications system. Telesat launched the ANIK AI and ANIK AII satellites in 1972 and 1973. ANIK AIII was launched in 1975. The ANIK A series was built by Hughes. Telesat has an ANIK B series under development by RCA and has plans for an ANIK C series.


Figure 5. Geosynchronous arc available to the United States, Canada and the other countries of the Americas, with identification of satellites.

In the United States studies showed that satellite communications could represent a viable means of domestic communications, and a number of system applications were submitted to the Federal Communications Commission in the late 1960's and early 1970's. After delays to resolve complicated legal, political and technical problems, the FCC authorized U. S. domestic satellites in a landmark ruling in December 1972, and rapid development of U. S. domestic satellite systems took place. Figure 6 shows the locations of current U. S. domestic common-carrier earth stations.

WESTAR I, the first United States domestic satellite, was launched by Western Union Telegraph Company in 1974. WESTAR II followed later the same year. Western Union has now installed five heavy-route and

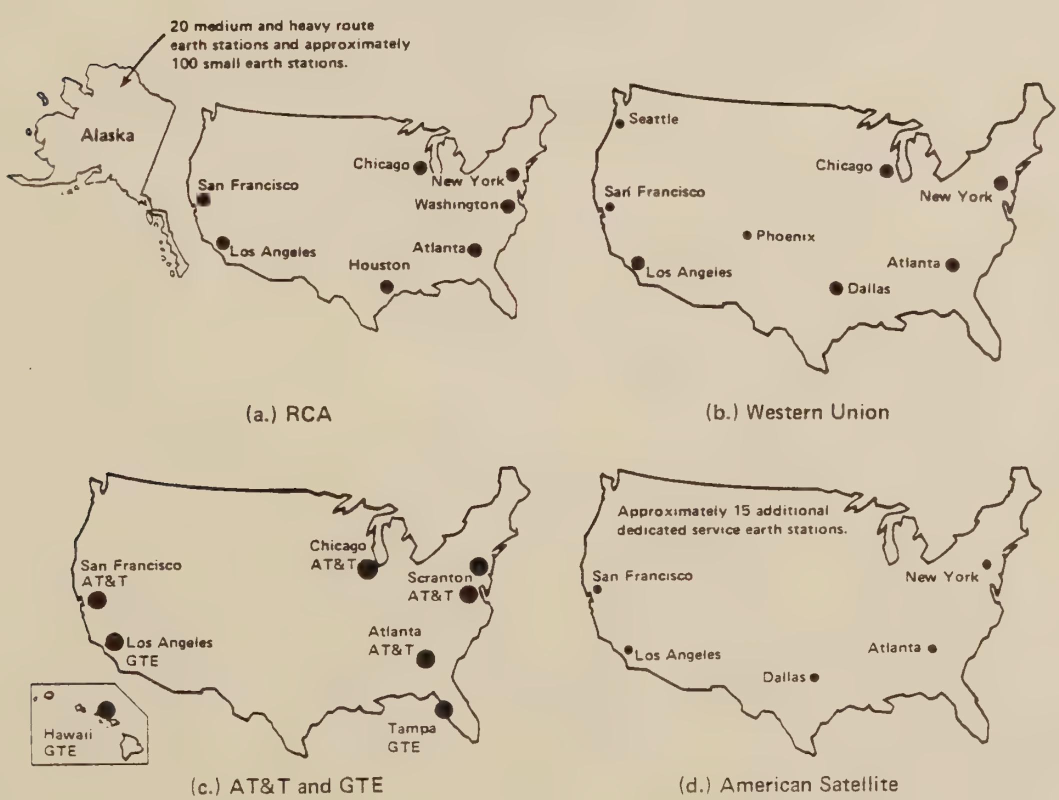



Figure 6. U. S. domestic common-carrier satellite earth stations.

three medium-route stations and leases extra capacity to other carriers. American Satellite Corporation leases transponders from Western Union and others for its system, which includes approximately nineteen earth stations, four for general common-carrier use and the remainder for dedicated service to military and commercial customers. Seven additional earth stations are under contract.

The entire capacity of the three COMSTAR satellites owned by Comsat General, a subsidiary of Comsat, has been leased by AT&T. The satellite system is used jointly by AT&T and GTE. AT&T has four earth stations and GTE has three providing long distance telephone transmission.

The first U. S. domestic satellite communications system actually in operation was established by RCA using the Canadian ANIK AII satellite. RCA's own satellites, SATCOM I and SATCOM II, were manufactured by the RCA Astro-Electronic Division and launched in 1975 and 1976. RCA American Communications owns and operates the RCA system. It leases satellite capacity to other organizations, and provides message and television services to business, the media, and government. It also leases raw transponders to RCA Alaska Communications (RCA Alascom) and other common carriers. It has 6 heavy-duty common-carrier earth stations and 16 stations dedicated to government users in the continental United States, and government stations in Hawaii and Greenland. RCA Alascom has approximately 20 heavy and mid-route systems in Alaska, and has installed approximately one hundred 4. 5-meter-diameter "bush" stations serving small rural Alaskan communities. The RCA earth station at Valdez, Alaska is shown in Figure 7.

Figure 7. RCA earth station at Valdez, Alaska.

In addition to the United States and Canada, other countries are turning to satellite communications to solve their communications problems. In 1976 Indonesia initiated service on its PALAPA-1 satellite, built by Hughes. Earth stations, supplied by Hughes and Ford Aerospace, have been installed at locations throughout the archipelago, and planning is in progress to extend the system with the addition of heavy-route stations for voice, teletype, data and video. In addition a large number of thin-route, two-way-voice and receive-only-video stations are planned. A second satellite, PALAPA-2, has been launched as a spare.

Nigeria has leased three INTELSAT transponders and purchased 19 receive/transmit earth stations from the Harris Corporation Satellite Communications Division to establish its own domestic satellite communications system. Any two of the 19 stations can simultaneously transmit message traffic or television programs to all the other stations. Figure 8 shows a typical Nigerian earth station.

Figure 8. A Harris domsat system in Nigeria.

The European Space Agency (ESA) has been engaged for a number of years in an extensive program of research and development which is directed toward strengthening European based space technology. France and Germany have cooperated in the development of SYMPHONIE, an experimental 6/4-GHz satellite, which is in operation in several programs over the Atlantic and Indian Oceans. The ESA Ariane launcher, scheduled for launch in June of 1979, will provide capability of launching heavy pay loads into synchronous orbit. The thrust of the European communications satellite development is toward the higher frequencies.

In addition to the systems discussed, there are a number of other foreign domestic systems in operation or under construction. The operational systems include systems in Algeria, Brazil, Norway, Sudan, Saudi Arabia and Zaire which use capacity rented from INTELSAT. The Philippine Islands have an operational system using capacity on Palapa-1 rented from Indonesia. The Government of India recently signed a contract with Ford Aerospace for the manufacture of two satellites for its domestic system, which is expected to be operational in 1981. An Arab regional satellite system (ARABSAT) is on the drawing boards. Table I is a summary of the status of domestic and regional satellite communications development throughout the world.

## Cable Television

Cable television (CATV) is responsible for much of the current growth in satellite communications. CATV started in the early 1950's to serve homes in rural areas and communities where reception tends to be poorer than in the big cities. Before satellite communications, CATV had made some inroads into the cities, but it did not have a lot to offer the big-city customer who had good off-the-air reception. With satellite communications the picture is entirely different. CATV can offer programs that viewers cannot otherwise receive, and a virtual explosion is taking place in the field.

Table 1. Status of Domestic and Regional Satellite Systems.

| Country | Utilizing INTELSAT | | | Dedicated Satellite | | | Remarks |
|---|---|---|---|---|---|---|---|
| | In Operation or Contract(s) Awarded | Active Plans | Study | In Operation or Contract(s) Awarded | Active Plans | Study | |
| Algeria | ● | | | | | | Operating |
| Australia | | | ● | | | ● | Study: 14/12 GHz |
| Brazil | ● | ● | | | | | Operating |
| Canada | | | | ● | ● | | Operating |
| Chile | ● | | | | | | |
| Colombia | ● | | | | | ● | |
| France/ Germany | | | | ● | ● | | Symphonie |
| India | | | | ● | ● | | Satellite Contract Awarded |
| Indonesia | | | | ● | ● | ● | |
| Iran | | | | | ● | | |
| Japan | | | | ● | ● | | |
| Malaysia | ● | ● | | | | | |
| Mauritania | | ● | | | | | |
| Mexico | | | ● | | | ● | |
| Nigeria | ● | ● | | | | | |
| Norway | ● | ● | | | | | Oil Field Communications |
| Oman | ● | ● | | | | | |
| Peoples Rep. of China | | | ● | | | ● | |
| Philippines | | | | ● | ● | | |
| Saudi Arabia | ● | ● | | | | | Operating |
| Spain | ● | | | | | | |
| Sudan | ● | | | | | | Contracts Awarded |
| Thailand | | | ● | | ● | | |
| Uganda | ● | | | | | | |
| United States | ● | | | ● | ● | ● | Plans for 14/12 GHz |
| U.S.S.R. | | | | ● | ● | | |
| Zaire | ● | | | | | | Contracts Awarded |
| ARABSAT | | ● | | | ● | | Regional |
| PAN AFRICAN | | | ● | | | | Regional |
| ANDEAN GROUP | | | ● | | | | Regional |
| ESA | | | | | ● | ● | Regional |

The rapid application of satellite communications techniques to the CATV industry provides a classic example of how the private enterprise system can function quickly to recognize and respond to consumer desires.

In late 1972, TelePrompTer Corporation became interested in investigating the feasibility of using the Canadian satellite, ANIK AI, to distribute programs via satellite. Scientific-Atlanta also became interested and entered into a contract to produce a transportable satellite earth station for TelePrompTer. This station was delivered in 1973 at the National Cable Television Association (NCTA) Convention in Anaheim, California, where it was used by TelePrompTer and Scientific-Atlanta to demonstrate convincingly the feasibility of satellite communications for CATV. Over the next several months, TelePrompTer used the station in demonstrations at about 30 of their system locations.

In December of 1974, representatives of Scientific-Atlanta met with representatives of Home Box Office (HBO), and with a major CATV operator and a domestic satellite carrier. HBO, a subsidiary of Time, Inc., was already distributing PAY-TV to CATV subscribers by terrestrial microwave. Western Union had launched WESTAR I and WESTAR II in 1974, and RCA was scheduled to launch SATCOM I in 1975. As a result of this meeting, it was made clear to all concerned that the elements for a network existed and that no long wait was necessary before implementation could be made a reality.

At the NCTA Convention in New Orleans in 1975, HBO announced its intention to distribute programming by satellite. At the same meeting UA-Columbia announced its agreement with HBO to receive satellite pictures in several of its system locations throughout the U. S. Receive

systems were purchased from Scientific-Atlanta by UA-Columbia and by American Television and Communications Corporation. HBO signed an agreement with RCA, which in turn leased space on WESTAR I for the initial programming on an interim basis. Programming was initiated on September 30, 1975 using WESTAR I, and was transferred to RCA's newly launched SATCOM II in the spring of 1976.

In 1976, HBO had about 500,000 total subscribers. Of this total 75,000 were served by a network of 45 satellite earth stations. At that time the minimum diameter permitted by the FCC for a CATV receive-only satellite earth terminal was 9 meters. In December of 1976 the FCC reduced the permissible diameter to 4.5 meters, decreasing significantly the cost of a TV receive-only earth station. HBO now has over 1,000,000 total subscribers, and 64 percent of their subscribers receive their programming by satellite. Thus their total growth is directly related to satellite distribution.

In December of 1976 the FCC granted a license to Southern Satellite Systems, Inc. to provide satellite common-carrier service of WTCG, Channel 17, Atlanta to cable television operators. The Southern Satellite Systems service includes all WTCG programming including live major-league sports broadcasts, syndicated programs and selections from a library of almost 3000 films. WTCG was seen by satellite in over 1,975,000 homes in mid 1978 and is expected to be seen in 3.1 million homes by January 1, 1979.

In addition to HBO and WTCG, the cable operator today can select from a number of satellite program alternatives. These include Showtime and Fanfare, religious programming presented by Christian Broadcasting Network, PTL, Trinity Broadcasting Network, programming from the Spanish International Network and special events from Madison Square Garden.

With multiple sources of programming even small cable systems can now economically justify the employment of satellite program services as an

integral part of their entertainment package for the home. CATV service is now available in about 14 million homes in the United States. Figure 9 shows U. S. CATV satellite receive-only earth stations which were installed or planned as of 1978. The map is necessarily only approximate because of the rapid rate of increase in the number of stations. Figure 10 shows the history and projected growth in the number of earth stations for the CATV industry. This projection shows approximately 2700 earth stations by January of 1981. With 12 of SATCOM I's 23 transponders already leased for video programming, and with 5000 CATV systems projected by that date, this projection is probably conservative.


Figure 9. U. S. CATV satellite receive-only earth stations installed or planned as of mid 1978.

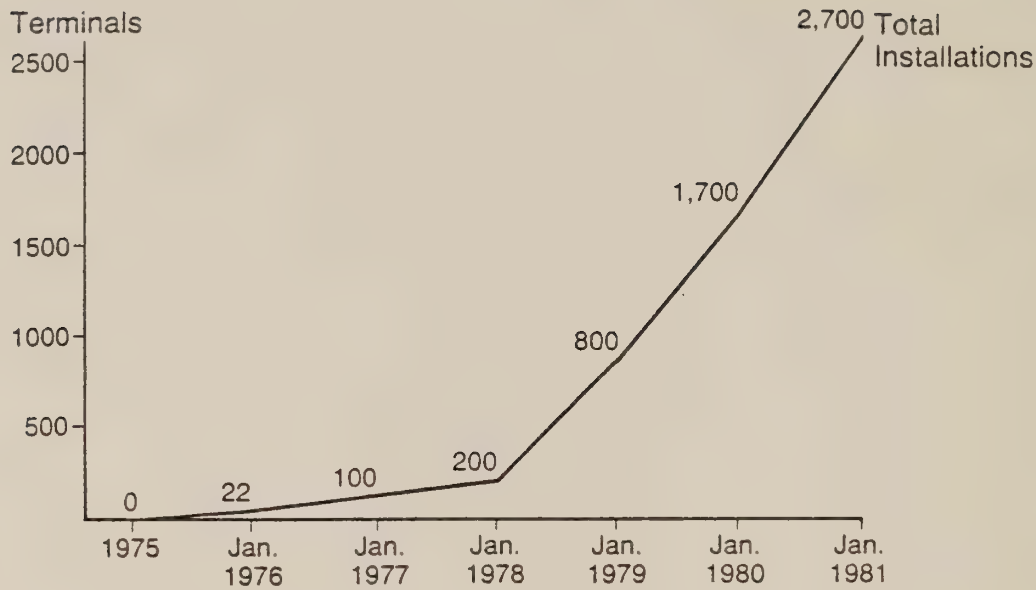



Figure 10. History and projected growth of CATV earth stations through January 1981.

## Television Distribution to Broadcast Stations

It appears that the broadcast industry will turn to satellites for program distribution as the CATV industry already has. ABC, CBS and NBC are all using satellite circuits to bring news pickups and sporting events from the field back to network centers -- and often to feed programs to regional distribution centers. In addition they use special circuits for feeding programs coast to coast and for a number of services for Alaska.

There are already several organizations distributing specialized programming to a selected group of stations either entirely, or primarily, by satellite. These include the Independent Television News Association (news stories), Spanish International Network (Spanish language programs) and Public Broadcasting Service.

Public Broadcasting Service is well along with its extensive satellite distribution program. It is installing facilities, which, when

completed in early 1979, will include the main transmit/receive earth station near Washington, six regional transmit/receive earth stations and 142 receive-only earth stations, linking 162 public television stations. See Figure 11. A number of these earth stations are already in operation.

PBS transmission will be via WESTAR -- starting with four full-time transponders. The economies are such that, after the earth stations are paid for, the annual cost of the four channels will be less than the cost of one terrestrial channel.

In addition to video programming, radio programming is also being carried by satellite. All the radio networks, as well as both AP and UPI audio news, are using satellite circuits between the east and west coasts. These are basically trunking circuits -- the kind of usage that was envisioned when communications satellites first came into use. Use of satellites is also probable for distributing radio programs to local stations.

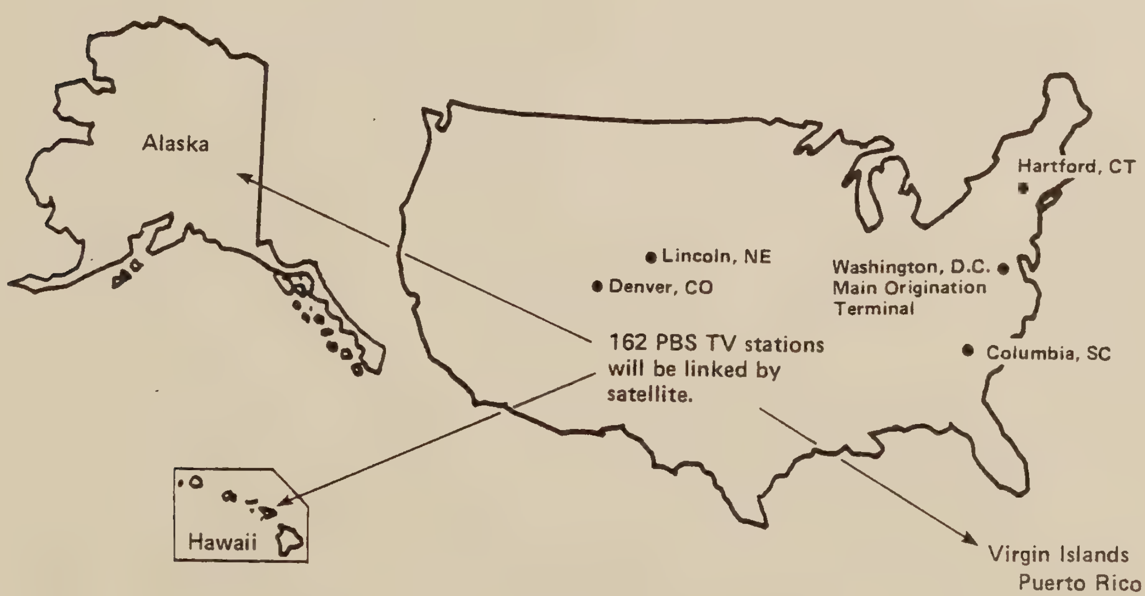



Figure 11. Public Broadcasting Service system, showing transmit-receive stations. The system is nearly complete.

Maritime Satellite Communications

Tremendous strides have been made in ocean surface shipping since World War II, as evidenced, for example, by the oil super-tankers. Until the MARISAT system was initiated in 1976 by the MARISAT Joint Venture*, radio communications with ships at sea was still in a primitive state, basically because of the uncertainty of ionospheric propagation in the HF region of the spectrum. The MARISAT system provides high-quality satellite communications services to the U. S. Navy and to the commercial shipping and offshore industries. The commercial system operates at approximately 1. 5 GHz between ship and satellite and in the 6/4 GHz band between the shore stations and satellite. Thus its performance is not affected by ionospheric disturbances, and contact with an equipped ship can be made at any time by any telephone or telex connected to the international system.

MARISAT provides telex and voice service with quality equal to or better than that of terrestrial circuits. It does not require constant attention by an operator and is as simple to operate as a telephone or telex machine. Its performance is contrasted with that of that of traditional radio telegraphy, where the average time for delivery of a one way message is six hours and the process involves highly trained radio operators at the shore stations and aboard ship.

Two MARISAT satellites are in commercial operation, one over the Atlantic Ocean and one over the Pacific. See Figure 12. Earth stations are located in Connecticut and California. There are already over 120 installations on board ship or on other installations such as oil drilling rigs. A third satellite is stationed over the Indian Ocean. It will go into

---

*The MARISAT Joint Venture is managed by Comsat General Corporation, and is comprised of Comsat General, RCA Global Communications, Inc. , ITT World Communications Inc. , and Western Union International, Inc.

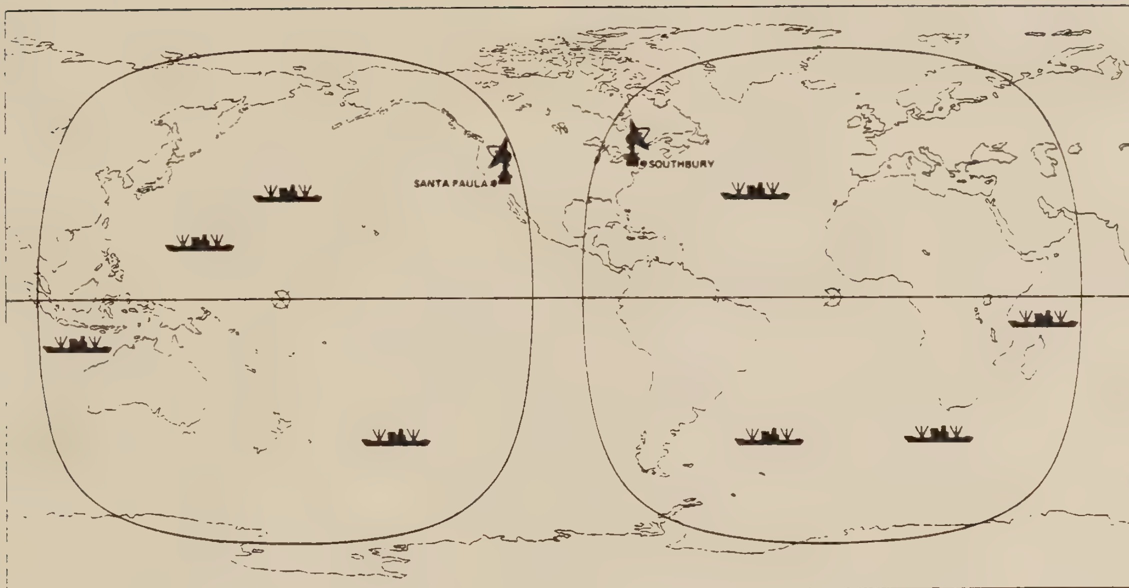



Figure 12. MARISAT coverage area and satellite locations mid 1978. A third satellite now over the Indian Ocean is to start commercial service in the fall of 1978.

commercial operation at about the time of publication of this issue, operating with an earth station in Japan. The MARISAT system can be extended for access of the satellites by multiple earth stations in the future.

Figure 13 shows a MARISAT antenna installed on the Esso Philippines. Figure 14 shows a control console and operating terminal. The MARISAT ship antenna is continually aimed at the satellite despite the ship's rolling, pitching, turning and changing geographic location.

The MARISAT system, designed and implemented primarily through the efforts of Comsat General, as manager of the MARISAT Joint Venture, and the efforts of its major contractors, Hughes, Ford Aerospace and Scientific-Atlanta, has revolutionized communications between ship and shore and represents the most significant advance in maritime communications in the past seventy-five years.

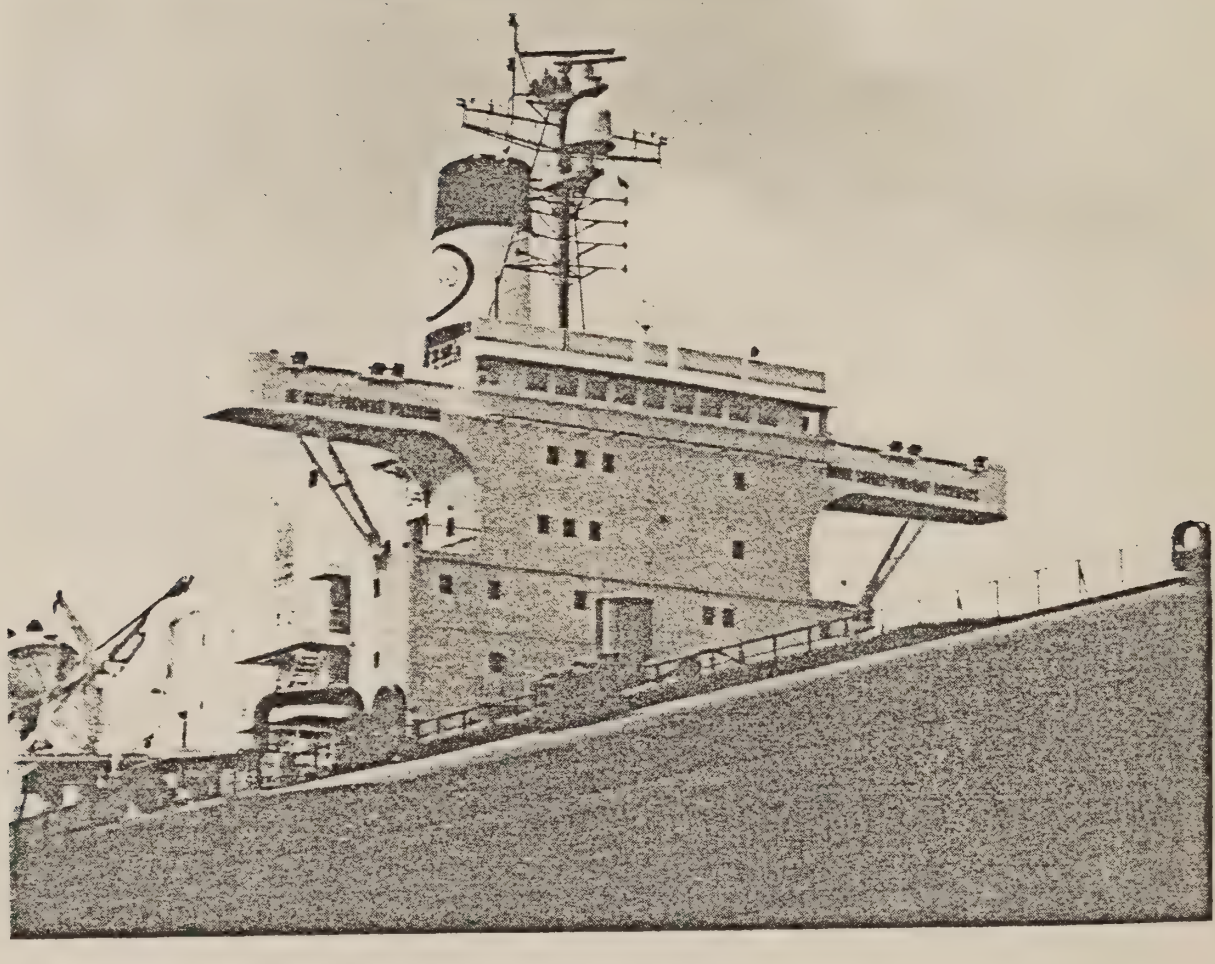


Figure 13. MARISAT antenna installed aboard Esso Philippines oil tanker.

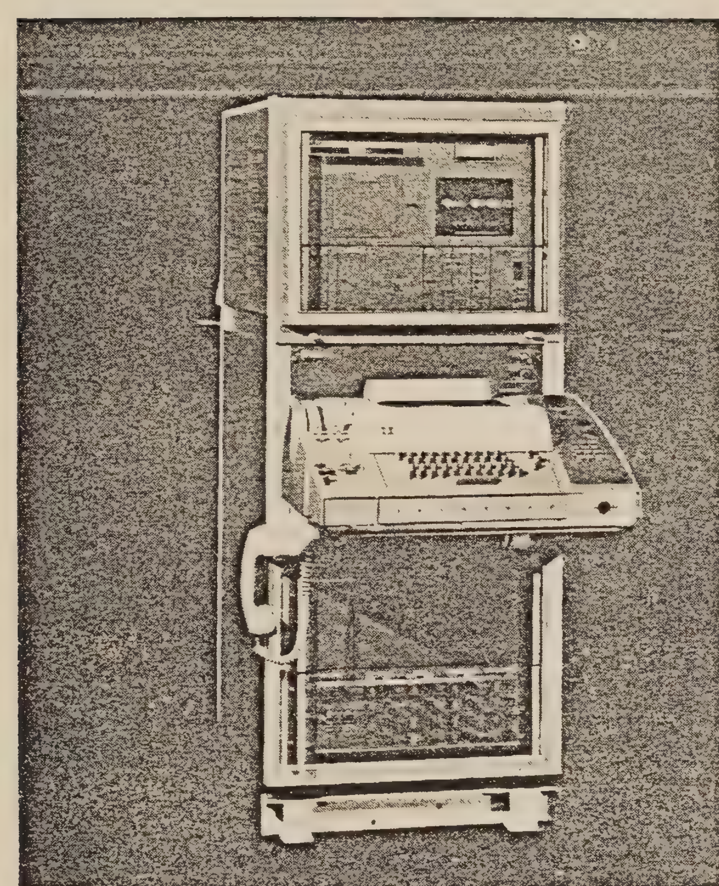


Figure 14. MARISAT Below Decks Console.

## Advanced Systems

Most of the current satellite communications systems use wide-band FM with frequency division multiplex and simultaneous access of the satellites by multiple earth stations using different frequencies (FDM/FM/FDMA). Other modulation and access formats have advantages for certain applications and are coming into use, especially in newer system designs.

The Single Channel per Carrier (SCPC) approach employs many closely-spaced carriers per transponder (typically 45 kHz or less), with a single voice-grade channel per carrier. Although this approach requires a high degree of frequency stability of the individual carriers, it permits installation of stations with as few as one voice-grade channel and with capability for additional of channels as required. Figure 15 shows a 120-channel SCPC Terminal manufactured by Scientific-Atlanta.

SCPC with Demand Assignment Multiple Access (DAMA) is a technique in which each earth station uses a channel only as it requires it. SCPC with DAMA is advantageous in low-demand situations. It is already in operation in the Intelsat SPADE system and on the Marisat system, and it is beginning to find increasing application in domestic and foreign thin-route systems.

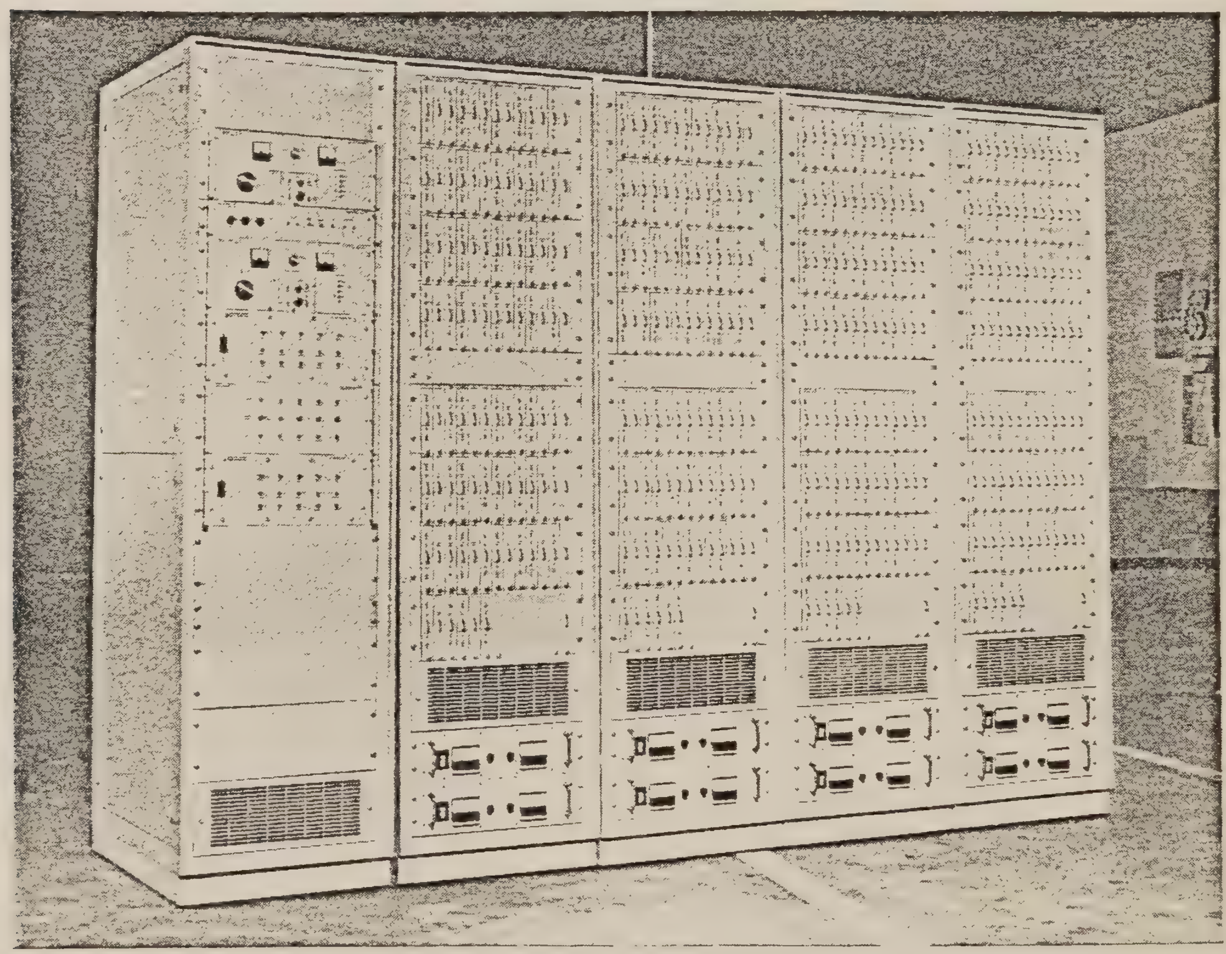


Figure 15. 120 Channel SCPC Terminal with redundant common equipment.

Delta modulation and biphase and quadriphase digital modulation (PSK and QPSK) formats are becoming increasingly important as advances in digital technology continue and as the costs of digital circuitry decrease. Systems with time division multiplex multiple access (TDMA) and SSTDMA (TDMA with satellite switching) are also in use or under development.

Satellite Business Systems (SBS), a partnership among wholly-owned subsidiaries of Comsat General Corporation, IBM and Aetna Life & Casualty Company, is implementing an extensive TDMA multipoint communications system using a single, time-shared carrier per transponder with transmission using QPSK in a burst mode. The system will operate at 12 and 14 GHz. This band is relatively sparsely populated, and has the advantage that earth terminals can be located inside cities without interference problems, rather than a number of miles away, as is usually necessary in the crowded 4- and 6-GHz band. Thus the earth stations can be located directly on customers' premises.

The increase in attenuation due to rain is a problem related to the use of 12 and 14 GHz. This factor is causing SBS to increase the concentration of energy over the heavy-rainfall eastern seaboard area. This increase in power density will permit use of 5-meter antennas in the heavy-rainfall areas.

Western Union will include a digital format with satellite switching and operation at 12 and 14 GHz in its next generation satellite, ADVANCED WESTAR, which is part of a shared space segment with the NASA TDRSS (tracking and data relay service system). The ADVANCED WESTAR segment will use high-gain spot beams in a switching-matrix to provide interconnectivity of six antenna beams in an SSTDMA system. The high gain provided by the spot beams helps overcome the problems caused by rain attenuation.

## Conclusions

The growth of satellite communications dramatically illustrates how the application of new technology to meet basic human and economic needs can benefit all segments of society. New markets and new jobs have been created while communications capabilities have increased and costs to the end user have decreased. We are still only beginning to realize the full potential of these developments.

The MARISAT system has produced a revolution in communications with ships at sea. It will continue to expand and is expected eventually to lead to an internationally owned and operated maritime satellite system technically compatible with the pioneering MARISAT system. Services to aircraft could be provided by the same or a separate system.

The use of satellites to distribute television programs to CATV systems continues to increase rapidly. The 2700 CATV earth stations planned for operation by January 1981 will be more than three times the number now installed. The sharp upward trend of this growth is directly attributable to the unique capabilities of satellite communications.

The exponential increase in digital techniques is already leading to a generation of multipoint satellite data networks. This trend will inevitably lead to universal access to data banks with the consequent exponential increase in the dissemination of knowledge and the rate at which new developments are made. Inherent to this growth are the increase in capabilities and decrease in costs of components and subsystems as large-scale integration enters the picture.

The growth of satellite communications has resulted from the timely bringing together of a number of technological developments, motivated by men who could see the political, economic, and human benefits to be achieved and who were willing to risk the expenditure of energies and resources to turn their imagination into reality. The short history of satellite communications has been exciting. The future holds great promise. Given a stable world politically and an economic climate that encourages the innovators, we can go farther in the next 15 years than we could now possibly predict.

# A SATELLITE PRIMER

Thomas J. Kelly
Applications Engineer
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## A SATELLITE PRIMER

If you are familiar with satellites and how satellite communication systems work you can skip this paper. If you are just getting acquainted, this paper, which covers the basics in lay terms, may be helpful. At the end of the paper is a Glossary of Terms frequently used in satellite communications along with some definitions and examples.

Although the mechanics of synchronous or geostationary satellites have been recognized for a long time - probably by Galileo or Copernicus - but implementation had to wait until the last half of the twentieth century, when the huge launch vehicles required were available.

The possibility of using synchronous satellites as a platform for a radio repeater was investigated in the early 1900's but had to wait until highly directive antennas and supersensitive VHF and microwave receivers were developed.

The first communications satellite was launched in 1965. In the succeeding thirteen years satellite communications has become commonplace and today the globe is covered by the INTELSAT system providing high quality voice, data and television communications on a worldwide basis. There are several regional satellite communications systems. For example RCA and Western Union have a total of four satellites providing message and TV service to the Continental U.S. and Hawaii. There are Comstar satellites starting message service to the same areas. The Canadians have been distributing TV by satellite for quite a few years via their ANIK satellites. The Indonesian PALAPA satellite has been in service for several years providing high quality voice communication and TV to the thousands of islands making up Indonesia. Other systems include the European Symphonie and the USSR satellites. In addition to the operating systems, dozens of other regional satellite systems are being discussed and planned.

Why has the art of satellite communication grown so much in such a short period of time? There is no one answer but several.

First, satellite communication is reliable and is not affected significantly by weather conditions, time of day, or sun spot activity as is the case with HF radio. Several times each year HF radio is useless for days for long distance communications because of sun spot activity, and even on the best of days is useable only for a few hours per day.

Secondly, there is no possibility of transmitting real time television by HF radio because of the bandwidths required and the serious selective fading experienced. At microwave frequencies the bandwidth is available for many TV channels and the fading problem is virtually non-existent.

Thirdly, satellites are by far the lowest cost means of communication over medium to long distances in comparison with terrestrial wire line, underseas cable, microwave, and coaxial cable. This cost reduction is dramatic when a TV program is to be transmitted to many receiving stations spread over a broad area, for example, the continental U.S. One further benefit is that since only one microwave repeater is involved, which is on the satellite, the picture equality can be far superior to one going through hundreds of terrestrial repeaters.

Now that we know of the veritable revolution in communication wrought by satellites, one asks - how is it done - what is a geostationary satellite - what does it do?

Our whole universe is made up of heavenly bodies that rotate around other heavenly bodies that rotate around other heavenly bodies. The moon rotates around the earth, the earth rotates around the sun and its likely that the sun

rotates around another sun, etc., etc. A man-made satellite is another moon and rotates around the earth. Gravitational laws, which control the universe, indicate that if a man-made satellite is closer to earth than a certain distance it will rotate around the earth faster than the earth rotates. Some meteorological satellites go around the earth in about 90 minutes. If the man-made satellite is located beyond a certain distance above the equator, it will rotate around the earth slower than the earth turns. For example our moon, which is more than 200,000 miles from the earth, requires over 28 days to make its rounds.

With this information it should be clear that if we could place a man-made satellite at the exact right distance from the earth, it would rotate at exactly the same speed as the earth, and if we could see it, it would appear to be fixed in the sky, and not move. The term synchronous satellite applies since the satellite is rotating around the earth in synchronism with the earth. The term geostationary relates to the fact that the satellite appears to be stationary in relation to a point on the earth. The distance above the equator where this phenomenon takes place is 22,300 statute miles. With todays rocket and guidance wizardry it is not difficult to precisely locate a satellite weighing a ton or more at a particular distance and location above the equator. Tiny jets in the satellite keep the satellite on its station.

Now if a microwave radio transmitter is put on the satellite with a broad beam antenna, called a global beam, slightly more than one-third the earth's surface would be covered by the signal from the satellite. If three such satellites are equally spaced (120° apart) around the equator the entire earth, except polar regions would be covered.

Why a microwave transmitter? Only microwave systems have the available bandwidth to transmit thousands of voice circuits plus several TV channels. Also, microwaves are not affected significantly by local weather conditions, the ionosphere or sun spot activity.

If instead of putting a microwave transmitter on the satellite, we put two microwave repeaters, we can send up a signal to the satellite which will repeat it (on a different frequency) back to the earth. We can use broad beam antennas on the satellite and can originate and receive the signal over the one-third of the earth's surface beneath the satellite. If we use narrower or shaped beam antennas on the satellite, coverages can be limited to certain areas such as the lower 48 states. Since we have two repeaters, or transponders as they are called, we can have two-way or duplex communication.

To reduce the earth station transmit power requirements and to permit reusing the microwave frequencies on other satellites spaced a few degrees away, earth stations typically use very high gain - narrow beam antennas. A 10 meter antenna for example reduces the transmitter power requirement to about one-two-hundred-thousandths of that required by an antenna radiating in all directions. Since the beam width is less than one degree, an earth station antenna aimed at one satellite will not cause interference to another satellite spaced approximately 4° away and operating on the same frequency.

The satellite antennas are shaped so that the desired coverage is obtained without wasting power by radiating it into space. This also provides some gain that reduces the satellite transmitter power to a few watts per channel. This is important since the satellite power is solar derived.

The high gain earth station antenna also collects the signal from the satellite which is nearly 100,000 times stronger than would be the case with a non-directional antenna. Even with this big boost, the satellite signal is very weak

and must be amplified in a very special amplifier that adds virtually no noise to the signal. This amplifier is called a low noise amplifier or LNA and may be a transistor type usually called a Gas Fet (GaAs FET) or a parametric amplifier. The signal gets about a 100,000 times boost in the LNA and is then sent to the receiver where the signal is amplified more and is demodulated producing the information originally transmitted - voice, data, or TV.

The foregoing is a very simplified expose of the mysteries of satellite communications. Naturally the art is far more complex than this and systems require sophisticated equipment, careful control of the satellite position, attitude and on-board housekeeping. Even with this complexity, suppliers have developed standard product earth stations that can be operated unattended, which continually tests themselves, instantaneously switch over to standby equipment in case of failure and summon help in case of trouble.

Where is satellite communications going? Due to the many advantages, particularly the demonstrated savings, it cannot help but grow and continue to take over circuits previously served by wire, coaxial cable, underseas cable, terrestrial microwave and HF radio. This is particularly true for medium to long distance and multiple destination systems. Thirteen years ago we had one tiny satellite capable of handling one TV program or several hundred telephone circuits. Today there are several dozen communications satellites some capable of handling up to 48 TV programs plus up to thousands of telephone conversations.

Present commercial communications satellites are approaching saturation and new and higher capacity satellites are planned as additions and as next generation satellites.

Figure 1 shows the present distribution of commercial domestic satellites within the 70° to 150° equatorial arc assigned for Western Hemisphere usage. There are a few other non-commercial satellites within the same arc some of which operate on the same frequency, thus occupy a slot.

All of the satellites shown in Figure 1 operate on 4 and 6 GHz. It will be noted that by using the 4° separation standard, slots exists for 20 satellites thus there are still quite a few slots available for more 4 and 6 GHz satellites.

There are other frequencies assigned for Domsat satellite work and the next to be used will be the 11 and 14 GHz bands such as for the SBS system. This will permit at least doubling the number of satellites occupying the 70° to 150° arc. Still other bands are available which will permit tripling or quadrupling the number of satellites that can be put into this 80° segment of the geostationary arc.

In addition to additional capacity available in unused slots and new frequencies, new techniques are available to more efficiently use the spectrum, thus putting more TV, voice and data channels on each satellite. Half transponder operation - a technique whereby two TV channels can be obtained in the bandwidth normally required by one TV channel - is being regularly used by INTELSAT and in Alaska and this technique will most likely expand - particularly with the new computer enhancement techniques now in the experimental stages.

Most everything seems favorable for satellite communications - it is generally lower cost - it permits high quality communications over long distances without outages - plenty of space is available for years to come - thus we expect a continued rapid growth and new technological breakthroughs to make it an even lower cost and more effective medium.

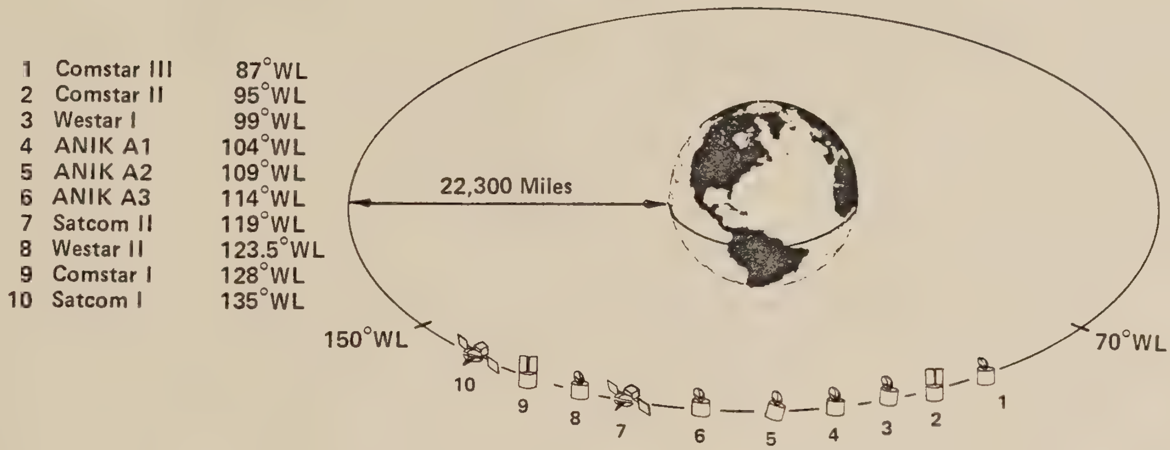



Figure 1. Western Hemisphere Domsats

# *GLOSSARY OF TERMS*

| | |
|---|---|
| *BER* | *Bit Error Rate.* In data transmission parlance, this is the measure of the number of errors expected in a data link. For example, a BER of $1 \times 10^{-6}$ means one error in each one million bits transmitted. |
| *C/N* | *Carrier-to-Noise Ratio.* The ratio of the received carrier power and the noise power in a given bandwidth, expressed in dB. This figure is directly related to G/T and S/N; and in a video signal the higher the C/N, the better the received picture will be (not to be confused with with $C/N_o$). |
| *$C/N_o$* | *Carrier-to-Noise Density Ratio.* Similar to C/N except that $N_o$ is related to the noise in one hertz of bandwidth. |

*dB* — *Decibel.* A term that expresses the ratio of two power levels used to indicate gains or losses in a system. Also used to express absolute power levels such as dBm or dBW.

The formula for determining the ratio in dB is

$$\text{Power ratio} = 10 \log_{10} \left(\frac{P_1}{P_2}\right) \text{ dB}$$

where $P_1$ and $P_2$ are the power levels

10 dB = a power ratio of 10

20 dB = a power ratio of 100

30 dB = a power ratio of 1,000

40 dB = a power ratio of 10,000

A power ratio expressed as a negative value, e.g., -10 dB, indicates a loss rather than a gain.

dBm and dBW express absolute power levels above one milliwatt (dBm) and above one watt (dBW).

| | | |
|---|---|---|
| 0 dBm | = | 0.001 watt or one milliwatt |
| 10 dBm | = | 0.01 watt or ten milliwatts |
| 20 dBm | = | 0.1 watt or one hundred milliwatts |
| 0 dBW | = | one watt |
| 10 dBW | = | ten watts |
| 20 dBW | = | one hundred watts |

*downlink* — The circuit between the satellite and the receiving earth station.

## *GLOSSARY OF TERMS - continued*

| | |
|---|---|
| *$E_b/N_o$* | *Energy-per-Bit-to-Noise Density Ratio.* In digital data work, this unit is an indication of the quality of the received signal and is directly related to BER or bit error rate. $E_b/N_o$ of about 12.5 dB, uncoded, yields a bit error rate of about 1 X $10^{-6}$ or one error in one million bits. Usually data systems employ forward error correction encoding which improves the BER by a factor of 1,000 or more. For example, 7/8 forward-error-correction encoding yields BER of 1 in $10^{-7}$, with an $E_b/N_o$ of 10.7 dB in some systems. |
| *EIRP* | *Effective Isotropic Radiated Power.* This term describes the strength of the signal leaving the satellite antenna or the transmitting earth station antenna, and is used in determining the C/N and S/N. When related to the satellite, it describes the strength of the satellite signal at any particular place on the earth's surface. Domestic satellite EIRP at any point in the contiguous 48 states ranges between 30 and 37 dBW.<br><br>For transmitting video earth stations, a minimum EIRP is required to properly excite the satellite and is of the order of 80 dBW.<br><br>EIRP may be increased either by increasing the transmitter power, or by using a larger and higher gain transmitting antenna. |
| *FDM* | *Frequency-Division Multiplex.* A method of multiplexing or combining many voice data channels for transmission on a single RF carrier. The channels are separated in frequency and are carried on subcarriers. |
| *FEC* | *Forward Error Correction.* An encoding scheme to improve the BER in a data system. In a typical Rate 3/4 FEC system, the BER may be improved by as much as $10^4$ or by a factor of ten thousand. |
| *frequency reuse* | See *polarization.* |
| *GCE* | *Ground Communications Equipment.* Relates to the earth station electronic equipment, such as receivers and exciters. |
| *G/T* | A figure of merit of an antenna and low-noise amplifier combination expressed in dB. *"G"* is the net gain of the system; and *"T"* is the noise temperature of the system. The higher the number, the better the system. |
| *HPA* | *High-Power Amplifier.* In a transmitting station, this is the final RF amplifier between the modulator/exciter and the antenna. For video use, this amplifier typically has a power output of 1000 to 3000 watts. |
| *$^oK$* | *Degrees Kelvin.* Temperature of a device measured in degrees Kelvin. $0^oK$ equals $-273^oC$ or $-459^oF$. The scale is the same as centigrade except that $0^oK$ is $-273^oC$. |

## *GLOSSARY OF TERMS - continued*

- LNA — *Low-Noise Amplifier.* This is the preamplifier between the antenna and the earth station receiver. For maximum effectiveness, it must be located as near the antenna as possible, and is usually attached directly to the antenna receive port.

  The LNA is especially designed to contribute the least amount of thermal noise to the received signal.

  LNAs are generally of three types as follows:

  a. *GaAs FET* (usually pronounced "gas fet"). A transistor amplifier using gallium arsenide, field-effect transistors. These are the lowest cost LNAs and those currently used have noise figures from 1.2 dB to 2.6 dB. These are highly reliable units.

  b. *Uncooled Parametric Amplifiers.* This is a much higher priced amplifier that has less noise contribution than GaAs FETs, thus, may be required in areas that have lower signal strengths (EIRP) from the satellite being used. These LNAs are also known as electronically cooled paramps and non-cryogenically cooled paramps.

  c. *Cryogenically Cooled Parametric Amplifiers.* These are parametric amplifiers that are actual cooled to near $0^{o}$K (-$459^{o}$F) by refrigeration equipment and which contribute the least amount of thermal noise. These are used in earth stations where the received signal is too weak to use the simpler and lower cost LNAs. Such LNAs are very expensive and require considerable attention.

*MATV* — *Master Antenna Television.* These systems are utilized in hotels, motels, and apartment complexes for television signal distribution.

*modem* — A contraction of modulator/demodulator. Usually a device that combines the modulation and demodulation functions in a single unit.

*MTBF* — *Mean Time Between Failure.* A statistical determination of the time in hours of use between failures. This is an indication of the reliability of the item described (subsystem or system).

*NF* — *Noise Figure or Noise Factor.* A term which is a figure of merit of a device, such as an LNA or receiver, expressed in dB, which compares the device with a perfect device. The lower the number, the better the unit. For example, a 1.5-dB LNA has better noise characteristics than a 2.6-dB LNA.

  The figure of merit of a device may also be expressed as noise temperature in degrees Kelvin or $^{o}$K. Again the lower the number, the better the unit. GaAs FETs typically have noise temperatures of $120^{o}$K (1.5-dB NF) to $238^{o}$K (2.6-dB NF), while uncooled parametric amplifiers typically have a noise temperature of $55^{o}$K.

*OMT* — *Orthomode Transducer.* A device attached to the antenna feed that permits using the antenna for simultaneous transmission and reception without mutual interference. The device is polarization selective; thus, the transmit and receive signals must be on different polarizations, usually orthogonally ($90^{o}$) related.

## *GLOSSARY OF TERMS - continued*

*polarization* A characteristic of the electric field of an electronmagnetic wave in space. Four senses of polarization are used in satellite work: horizontal linear, vertical linear, and RH and LH circular. The satellite and earth station polarizations must match, and an antenna feed adjustment is made at the time of installation to match the horizontal or vertical polarization of the satellite antenna. No adjustment is required for circular, except that both antennas must be for right-hand circular or left-hand circular.

Two signals in space on the same frequency can be separated by having a 90° (orthogonal) difference in their polarization, e.g., by vertically polarizing one and horizontally polarizing the other. This technique, which essentially doubles the capacity of a satellite, is used on several Domsats. Since two signals use the same frequency, but with orthogonal polarization, the technique is known as frequency reuse.

A special antenna feed known as a frequency reuse feed is required in systems using this technique.

*protection* See *redundant.*

*redundant* In satellite parlance, this means that extra subsystems are included that are used to automatically and almost instantaneously replace a failed or degraded subsystem. For example, LNAs are almost always supplied in pairs with a switchover system. Should the on-line LNA fail, sensors detect the failure causing the standby or redundant LNA to be switched on-line. Generally this takes place in less than one third of a second.

The term "protection" is also used in this context. The standby LNA, in this case, protects the on-line LNA.

Redundancy or protection may be of the 1:1 or 1:N type. Where one standby subsystem is provided for each on-line unit, the protection afforded is 1:1 or one for one.

Where several identical on-line subsystems are involved; e.g., four video receivers receiving four different programs, one additional subsystem may be provided to automatically replace any one of the on-line subsystems that may have failed. This is 1:N, or one for a number (N), protection.

The 1:N protection switches are rather complex and are more expensive than 1:1, but reduce the number of standby subsystems required in a system involving several identical on-line subsystems.

*RF* *Radio Frequency*

*RX* *Receive or Receiver.*

*SCPC* *Single Channel Per Carrier.* A satellite transmission system that employs a separate carrier for each channel. Generally this method is used at earth stations that have a low volume of traffic that can be handled by considerably fewer channels than is used in a typical frequency-division multiplex system that can multiplex up to near two-thousand voice channels on a single RF carrier.

## *GLOSSARY OF TERMS - continued*

S/N — *Signal-to-Noise Ratio.* The ratio of the signal power and noise power. A video S/N (Signal-to-Noise Ratio) of 54 to 56 dB is considered to be an excellent S/N, that is, of best broadcast quality. A video S/N of 48 to 52 dB is considered to be a good S/N at the headend for Cable TV.

TED — *Threshold Extension Demodulator.* A scheme for lowering the threshold of FM (frequency-modulated) demodulators, permitting operation of the system with a lower C/N without impulse noise showing on the picture. This device is used when the C/N is below 13 dB, and is generally used in small antenna (5-meter) receive-only earth stations.

TX — *Transmit or Transmitter.*

TVRO — *Television Receive-Only* earth station.

UPLINK — The circuit between the transmitting earth station and the satellite.

# VIDEO EARTH STATION EQUIPMENT – AN OVERVIEW

Ken Leddick
Senior Marketing Manager
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

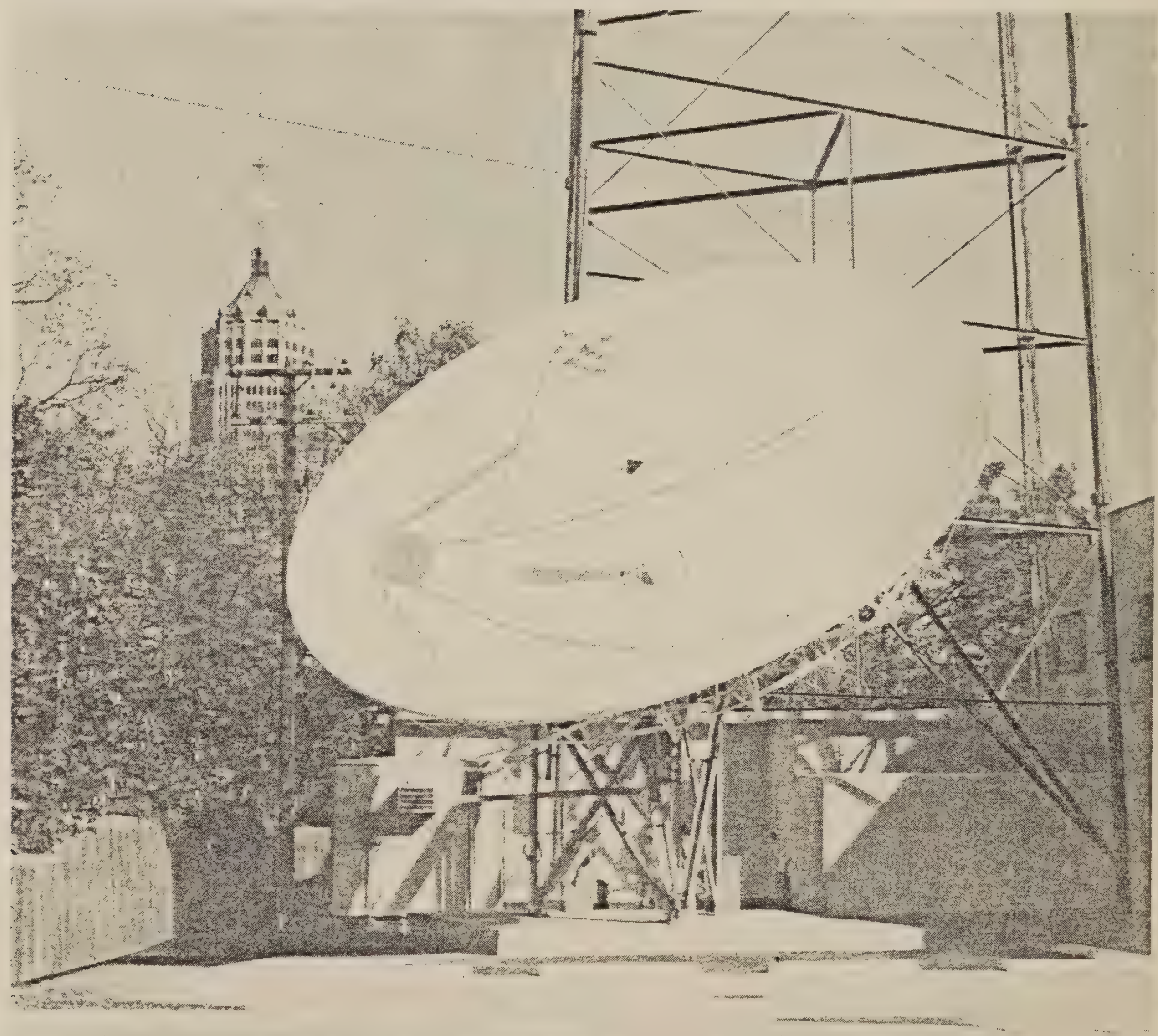
Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## VIDEO EARTH STATION EQUIPMENT — AN OVERVIEW

The use of synchronous satellites for video programming distribution is a concept which has been reducing costs and improving the quality and reliability of transmissions for several years. Various earth station types are in service around the world, ranging from the basic single channel video receive-only station to highly redundant multi-channel stations capable of simultaneously transmitting and receiving multiple video and message signals. Antennas in commercial use for transmitting and receiving video range from the complex 30 meter diameter structures used for international traffic to relatively simple small diameter antennas in the 4.5 to 5 meter range used extensively by CATV operators.

This paper defines the basic hardware required for several of the most common video earth station configurations. An in-depth technical discussion of each component will be presented by Scientific-Atlanta's engineering experts later in the conference.



KWEX-TV Spanish International Network, San Antonio, Texas

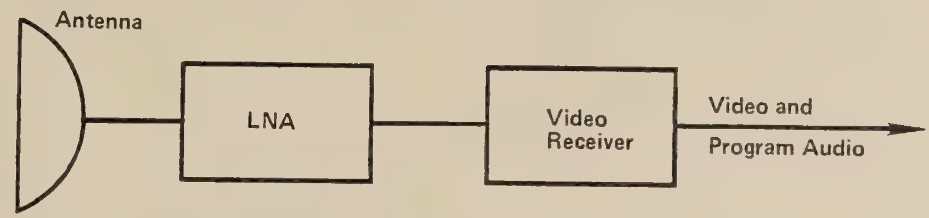



Figure 1. Basic Non-Redundant Earth Station Configurations

**Basic Receive-Only Earth Station Components**

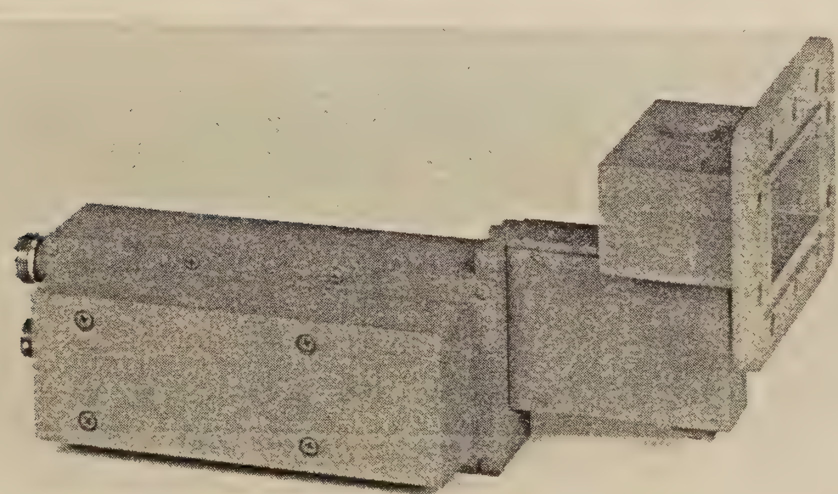
The most basic receive-only video earth station consists of an antenna, a low noise amplifier (LNA), a video receiver, and miscellaneous interconnecting cabling as shown in Figure 1 above.

The LNA, which is typically attached directly to the antenna feed, accepts the incoming 4 GHz downlink signal from the antenna and amplifies this signal for input to the video receiver.

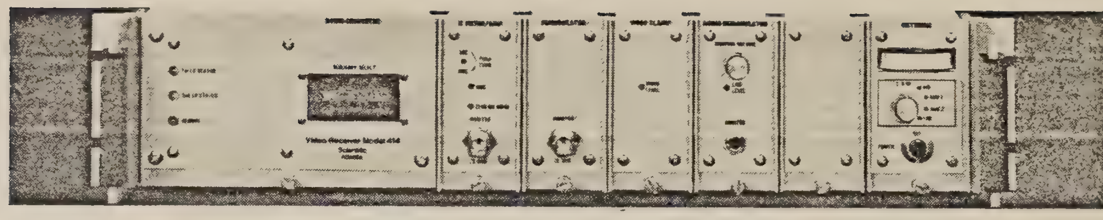
The video receiver is connected to the LNA by coaxial cable, and may be located several hundred feet from the antenna. This receiver selects the desired incoming 4 GHz frequency modulated carrier with color video and audio, downconverts and demodulates the signals to the baseband frequency, and clamps the baseband output.

Additional video program material carried by other transponders on the same satellite may also be received simply by inserting a power divider in the coaxial transmission line just ahead of the receiver and adding additional receivers to the basic receive-only system. No changes to the antenna or LNA are required providing all programming being received is carried on transponders with the same polarization.

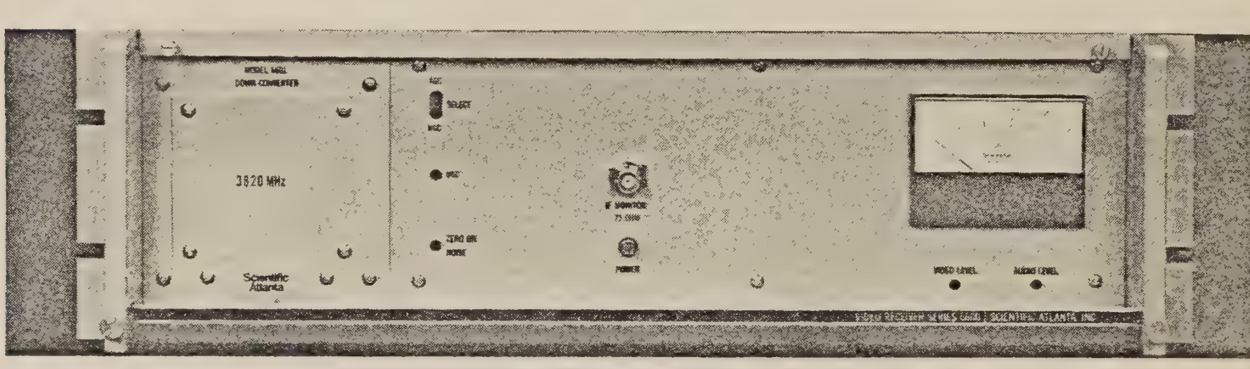
Some satellites are designed to expand the number of available transponders from 12 to 24 by using a frequency reuse technique. In these satellites, the polarization of even numbered transponders is opposite the polarization of odd numbered transponders to provide the required isolation between reused frequencies. The earth station antenna must be equipped with a dual polarized feed, and a second LNA and coaxial cable run must be installed if simultaneous programming is to be received from transponders on both polarizations.



GaAs FET Amplifier (LNA)



Model 414 Frequency Agile Video Receiver



Model 6601 Fixed Frequency Video Receiver

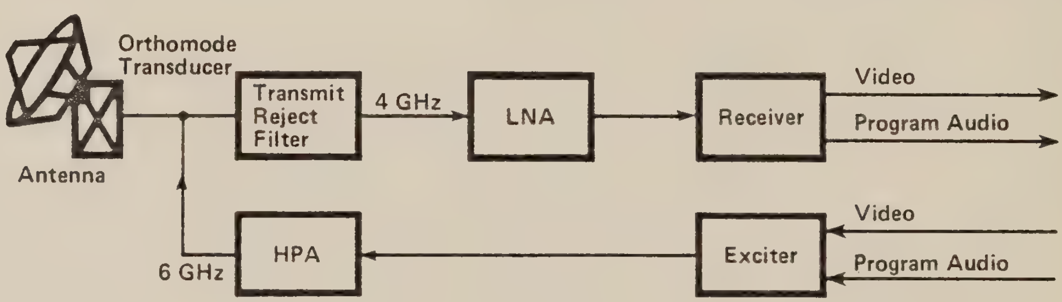



Figure 2. Basic Transmit/Reveiver Earth Station Block Diagram

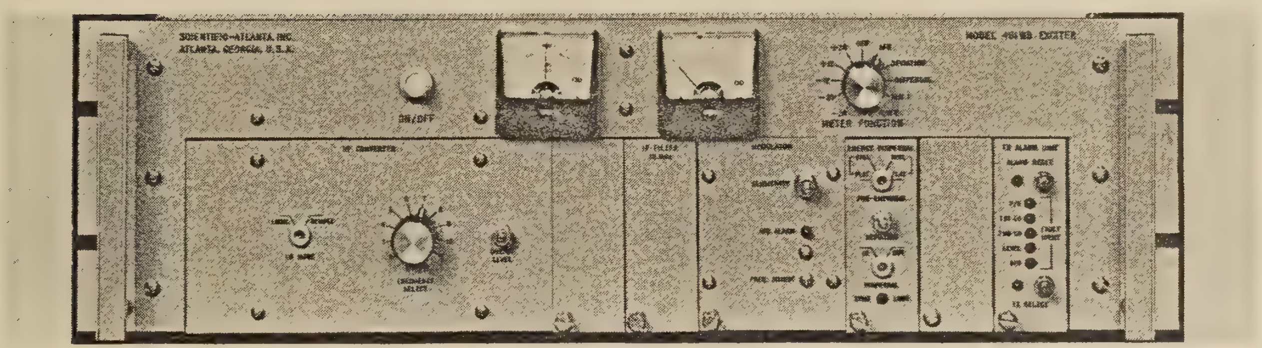
### Basic Transmitting and Receiving Earth Station Components

The basic transmitting/receiving earth station contains all the receiving equipment discussed above plus the addition of a video exciter, high power amplifier (HPA), transmit reject filter, and interconnecting transmission lines. The earth station antenna feed must also be equipped with an orthomode transducer to permit simultaneous transmission and reception through a single antenna.

The video exciter accepts the baseband video and program audio signals and modulates and upconverts these signals to the proper channel in the 6 GHz frequency band. The HPA accepts the output from the video exciter and amplifies this signal to the required power output level. Output power levels for video earth station HPA's typically range up to 3 kilowatts.

The HPA is connected to the antenna 6 GHz input port with waveguide, and the total waveguide run length must be minimized (usually less than 50 ft.) to prevent excessive losses.

The addition of a second video uplink to the basic station requires an additional video exciter, HPA, and a combiner; and is somewhat more expensive than adding downlinks.



Model 461 Video Exciter

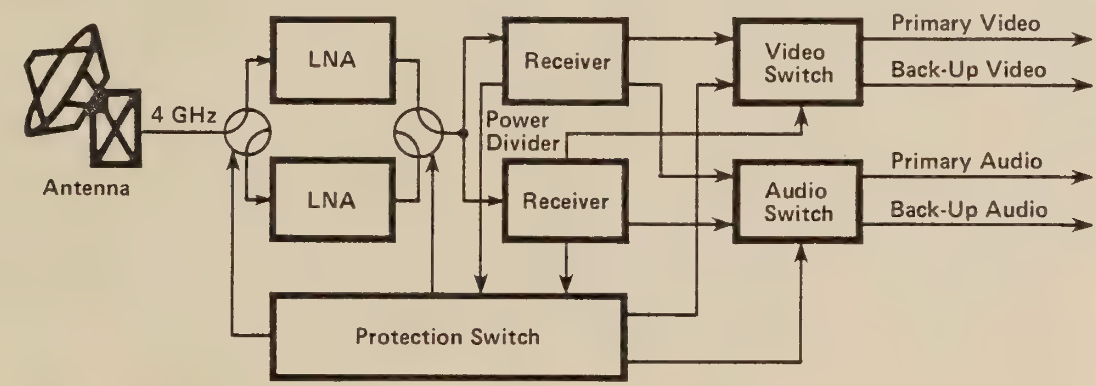



Figure 3. Redundant Receive-Only Earth Station Block Diagram

## Redundant Video Earth Station Configurations

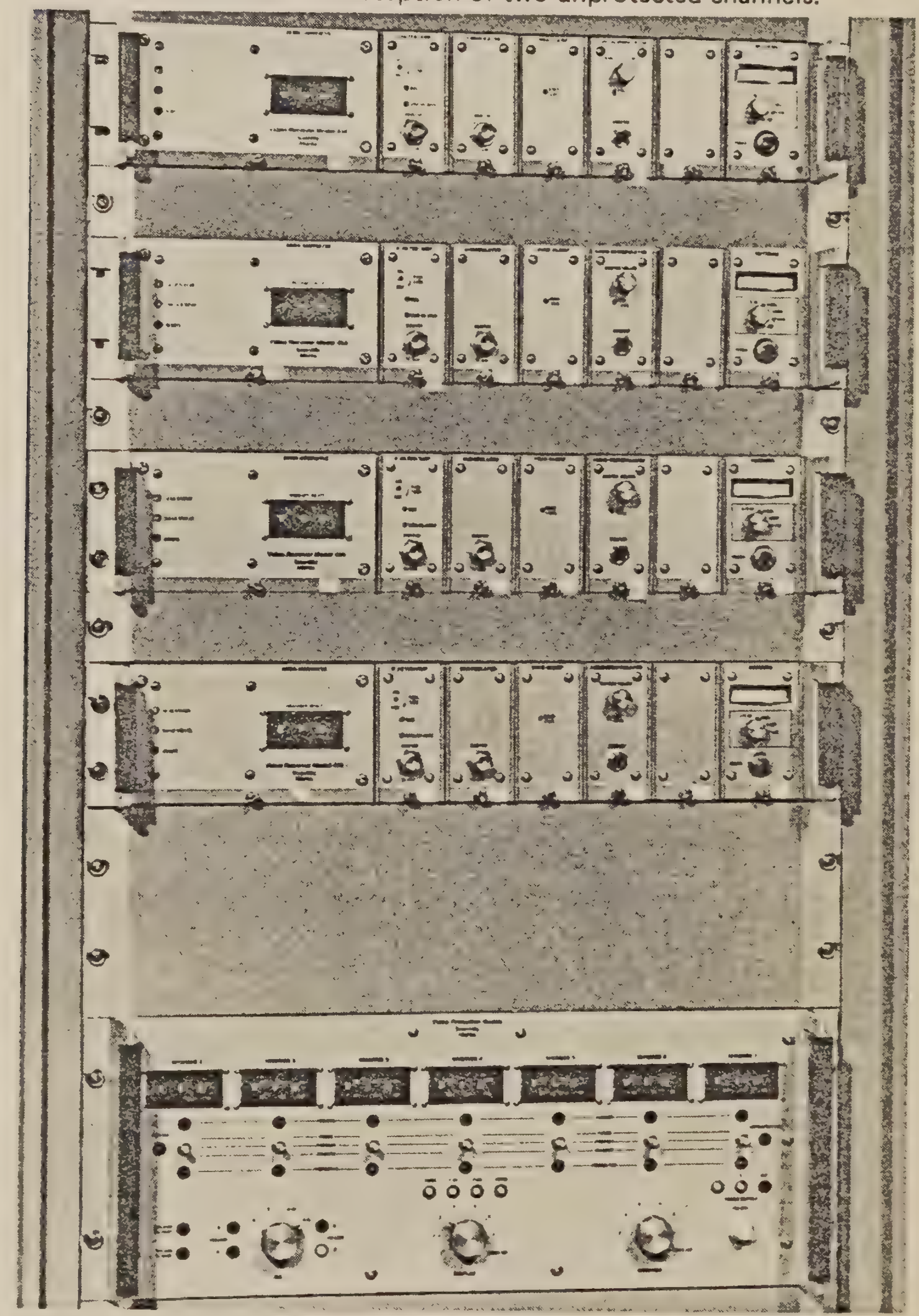
Earth stations designed for use in applications requiring higher system reliability include standby electronics as well as automatic fault detection and switching equipment.

The redundant receive-only video earth station shown in Figure 3 contains the same basic equipment as a non-redundant station plus the addition of a standby LNA and video receiver. A video protection switch is also included to monitor the primary LNA and receiver for proper operation, and to automatically switch to the standby units should problems develop.

Video protection switches may also be configured in the 1:N protection switching mode to minimize the standby electronics required for multiple channel operation. In a 1:N system, one frequency agile standby receiver is automatically switched and re-tuned to provide protection for up to N (typically 7) on-line receivers.

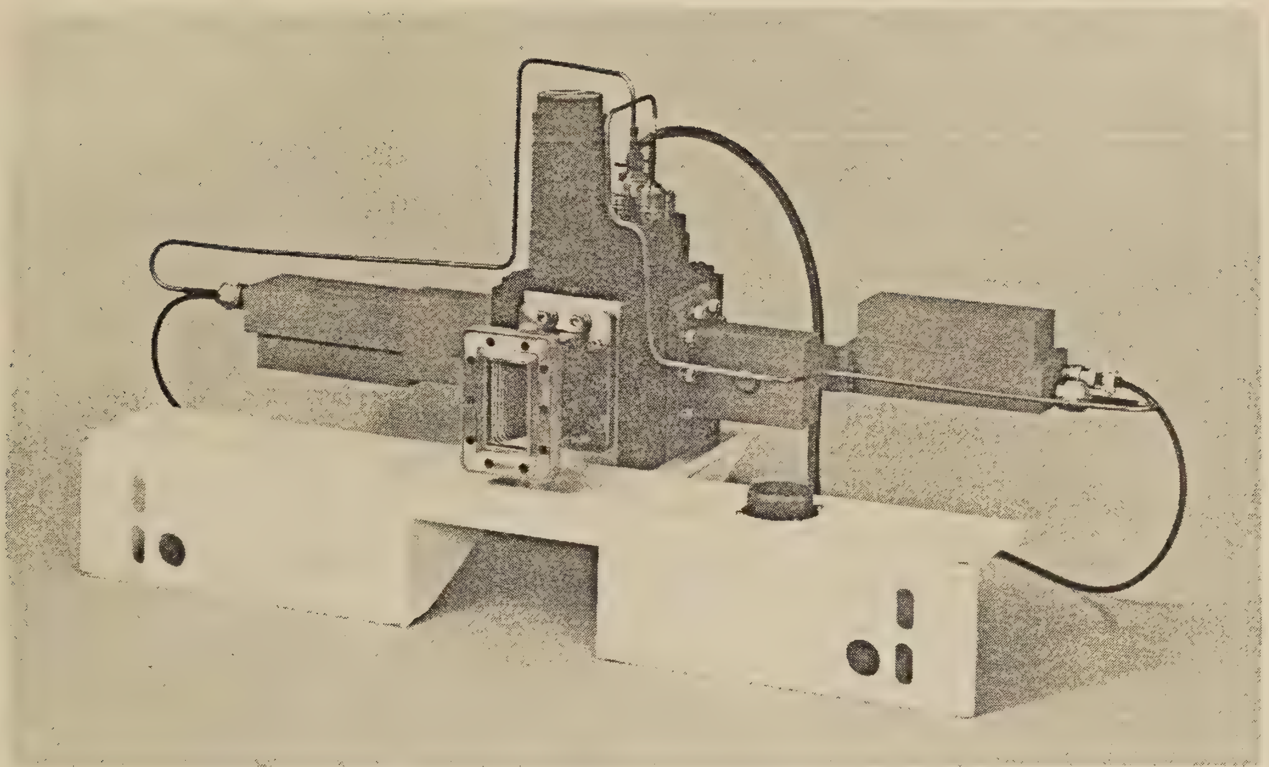
Redundant receive only earth stations also provide considerable operational flexibility for the owner. For example, the system shown in Figure 3 may be operated in any of the following modes from time to time:

a. The system may be operated in the fully protected mode with automatic LNA and receiver switching for maximum protection against system outage.
b. Protection switching may be set to allow simultaneous operation of one primary and one secondary channel. The secondary channel is automatically pre-empted and switched into primary service if needed for protection of the primary channel.
c. The protection switching may be set in the override position to allow occasional simultaneous reception of two unprotected channels.



Multiple Channel Downlink Consisting Of:

- 3 Operating Channels
- 1 Protection Channel
- 1:N Protection Switch



Antenna Mounted Redundant LNA's With Input and Output Switching

**Redundant Transmitting and Receiving Station**

The downlink portion of a redundant transmitting and receiving earth station shown in Figure 4 is identical to the redundant receive-only station and offers the same operational flexibility.

The uplink contains a standby video exciter and HPA as well as automatic monitoring and switching for high system reliability. Also the uplink protection switching is typically configured to permit simultaneous transmission of multiple video uplinks through the combiner shown in Figure 4.

The uplink portion of the redundant earth station also provides considerable operational flexibility. A single uplink channel may be operated in the full hot standby mode with automatic switching, or a secondary channel may be operated simultaneous with a primary uplink and pre-empted if necessary for protection of the primary channel. Also protection switching override may be selected to allow simultaneous transmission of two unprotected uplinks.

Scientific-Atlanta has delivered and installed numerous redundant video earth stations. These systems are now being used to transmit video programming to the satellite and for reception of this programming at CATV systems and commercial broadcast stations throughout the country.

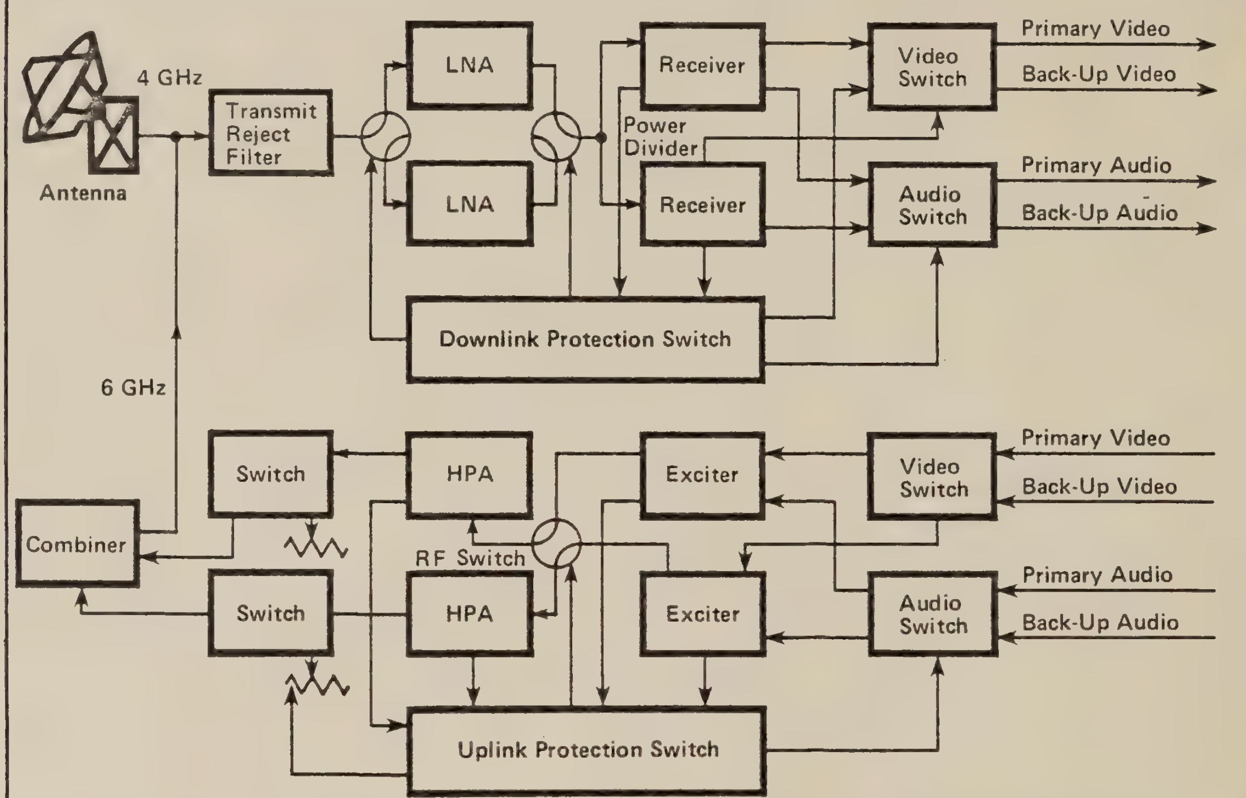
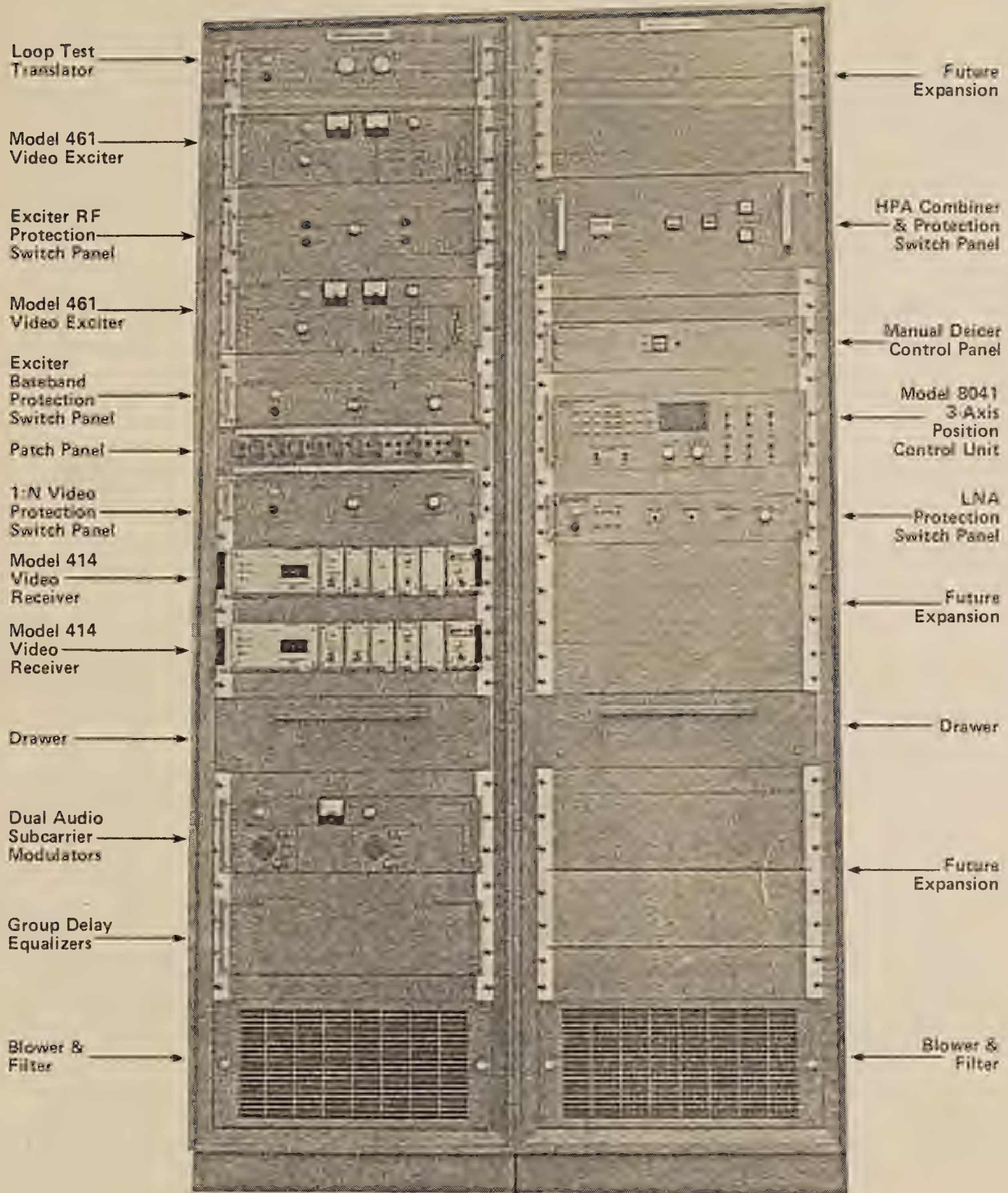



Figure 4. Redundant Transmit/Receive Earth Station Block Diagram




Redundant Transmit/Receive Video Earth Station Electronics per Figure 4 Block Diagram (less HPA's)

## Earth Station Antenna Types

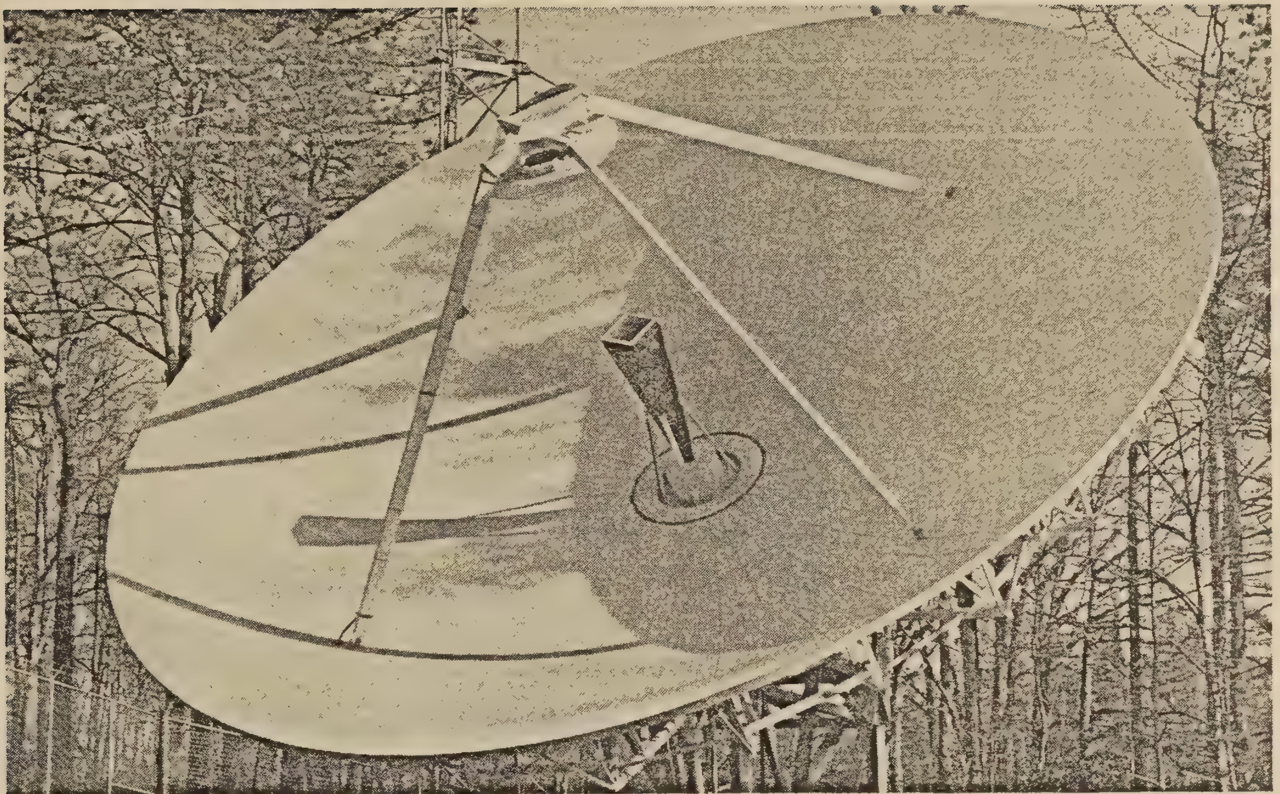
Earth station antennas can be equipped with receive-only or transmitting and receiving feed systems. Various feed configurations are common today; and the antenna feed chosen for a particular earth station depends on several factors including performance objectives, frequency coordination, and future earth station traffic requirements.

Receive-only earth stations can be equipped with either a dual reflector Cassegrain feed or a prime focus type feed system.

The prime focus feed system consists of a radiating source located precisely at the focal point of the parabolic reflector and supported from the main central hub of the antenna by reinforced feed mounting mast. This type of feed can be designed to produce excellent sidelobe radiation characteristics with only a small sacrafice in gain. As a result, the prime focus feed is especially useful for video earth stations where it is most desirable to locate the antenna on existing property near cities or other areas that may be congested with potentially interfering terrestrial microwave traffic.

10 and 5 Meter Diameter Antennas

The Cassegrain feed system consists of a horn radiating source located at the center of the main reflector and a specially shaped subreflector located in front of the main reflector and supported by spars. RF energy is radiated from the horn source to the subreflector, reflected back to the main reflector, and then reflected again toward the satellite. This type of feed is somewhat more efficient than the prime focus feed and is most useful for systems requiring the highest RF performance.



10 Meter Antenna with Cassegrain Feed.

Cassegrain type feed systems are recommended by Scientific-Atlanta for small diameter video earth stations in the 5 meter size range since maximum antenna efficiency is important to the overall performance of these stations. Cassegrain feeds are also used almost exclusively for antennas that transmit and receive to obtain higher efficiencies and minimize waveguide run losses.

**Low Noise Amplifiers**

The actual LNA selected for a video earth station depends on the satellite signal strength at the site, the antenna size, and the desired signal to noise ratio. Practical choices for video earth stations range from non-cryogenically cooled parametric amplifiers with noise figures of 0.8 dB and less to GaAs FET amplifiers with noise figures in the 1.5 - 2.6 dB range.

The low noise parametric amplifiers can now provide overall noise performance approaching that of a cryogenically cooled amplifier, but without the latters refrigerator, compressor, and vacuum enclosures. These units use two identical paramp stages followed by a post amplifier to obtain a total passband gain in the 50 dB range. Limitations of these paramps when compared to the higher noise figure GaAs FET amplifiers include higher initial cost, more frequent maintenance requirements, and the increased need for a redundant or standby amplifier.

GaAs FET amplifiers have been provided by Scientific-Atlanta for use in CATV and broadcast earth station systems throughout the United States. The basic advantage of these amplifiers are low initial cost, no periodic maintenance requirements, and mean time between failure (MTBF) rates significantly superior to parametric amplifiers.

There is a definite cost versus performance and maintenance tradeoff for the various configurations of antenna sizes and LNA types available on the market today. These comparisons will be discussed in more detail during a following session on receive system performance calculations.

**Optional Equipment for Video Earth Stations**

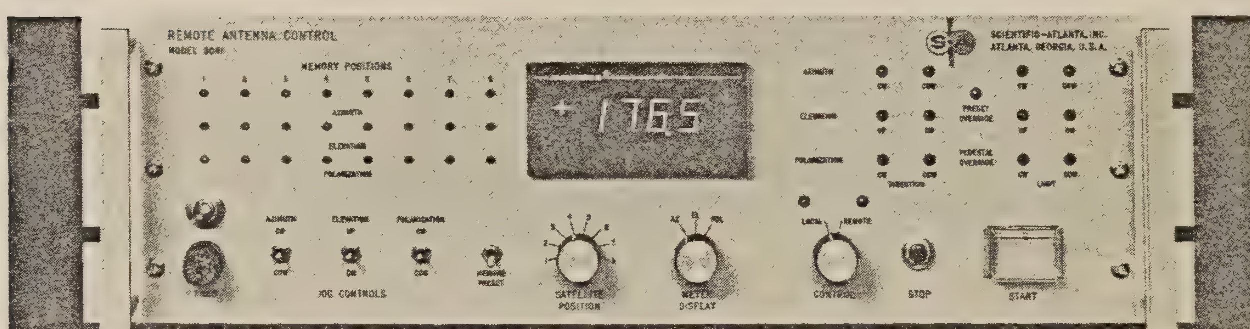
A variety of optional accessory items are available for video earth stations to simplify operation, provide special features, and improve overall system reliability. Following is a list of some of the most common optional accessories with typical applications for each item:

1. Motor drives for positioning the antenna azimuth, elevation, and polarization axes.

   Earth stations operated by television broadcasters and common carriers are usually equipped with motor drives to permit operation with various satellites on a per event basis. Earth stations for CATV operators are not motorized since all programming is usually received from a single satellite.

2. Automatic Antenna Position Controller.

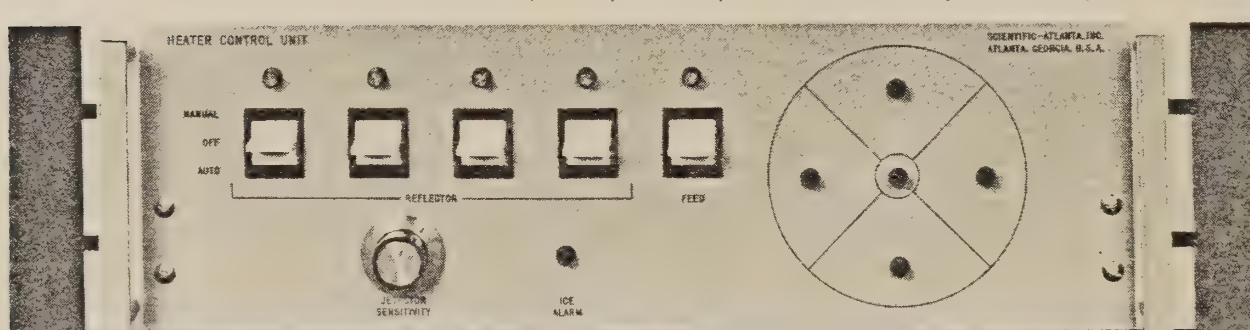
   For earth stations equipped with motor drives, the automatic position control unit greatly simplifies the movement of the antenna between satellies. Scientific-Atlanta's Model 8041 Automatic Position Control Unit is used by many television broadcasters to provide hands-off automatic antenna control for up to eight individual satellite positions. This controller is usually rack mounted with the video receivers, and it may be operated remotely through a wire line or radio link remote control system.




Model 8041 Automatic Antenna Position Control Unit

3. Automatic deicing equipment for the antenna feed and/or main reflector.

   In some areas deicing of a portion of the earth station antenna is necessary to maintain adequate system performance during snow and icing conditions. For more severe climates this usually consists of deicing equipment for the antenna feed and for the lower half of the main antenna reflector. In other areas, it may be acceptable to deice only the feed system.



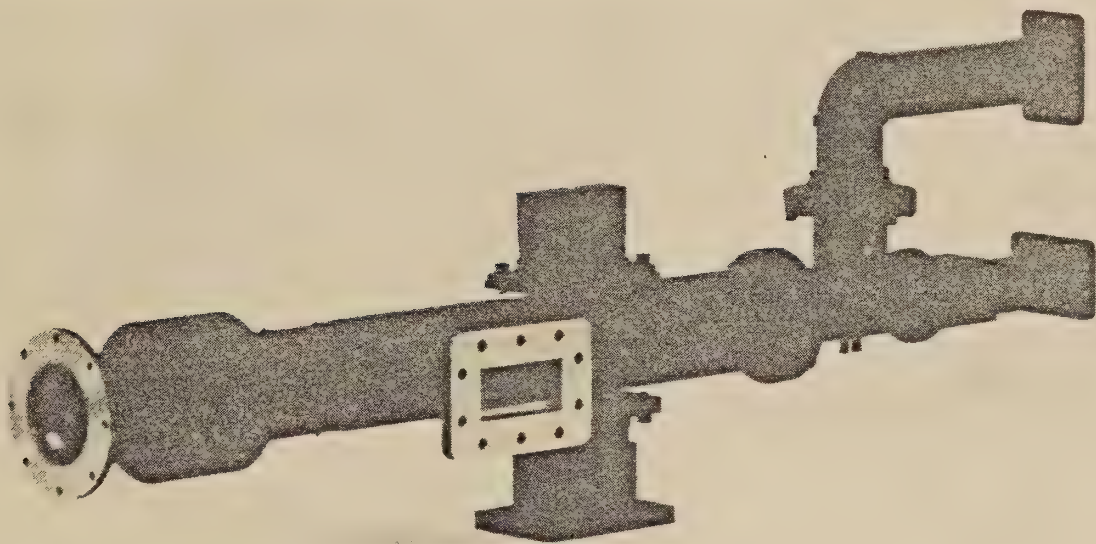

Series 8240 Deicing Control Unit

4. Threshold extension demodulators for video receivers.

   These units are used to automatically extend acceptable picture quality to lower operating signal levels. Typical applications include earth stations using small diameter antennas in the 5.0 meter diameter size range, and for larger diameter stations located in low satellite signal strength areas.
5. Cue channel equipment to provide a voice grade channel in addition to the normal program audio subcarrier.

   Cue channels are typically used by broadcasters and common carriers to transmit system operational instructions.
6. Frequency reuse antenna feeds.

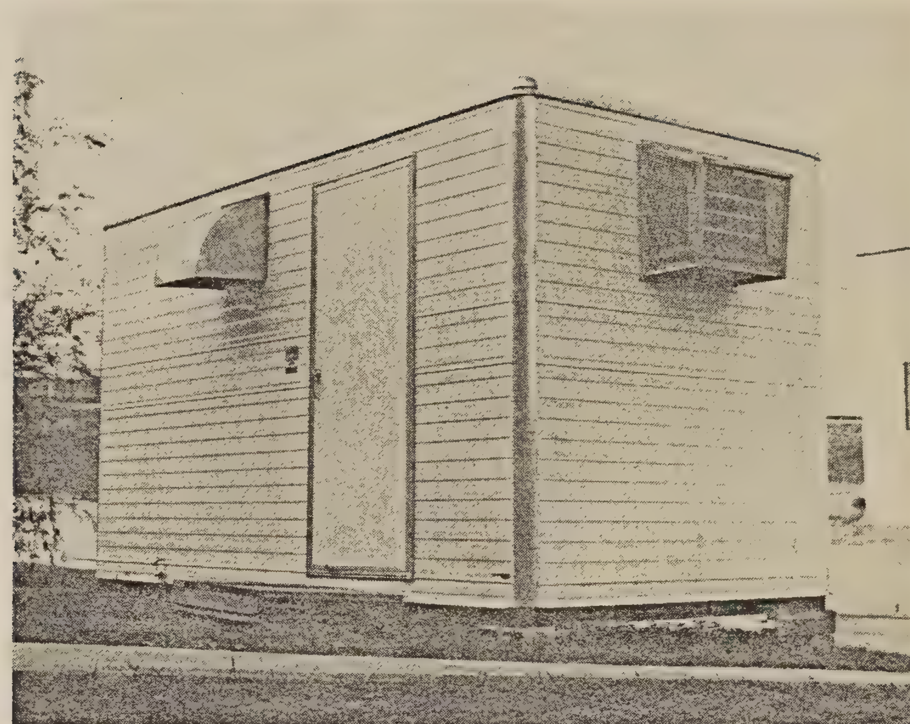
   Special frequency reuse feeds such as Scientific-Atlanta's Model 8230 Feed are available for transmitting and receiving earth stations to permit simultaneous access to all 24 transponders on a frequency reuse satellite.



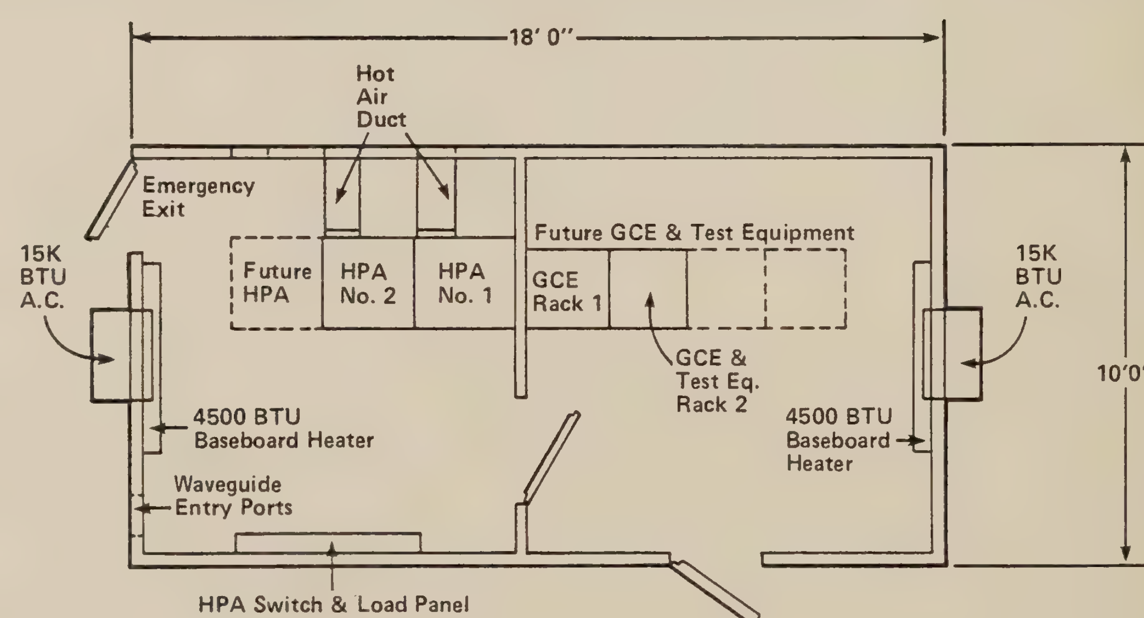
Model 8230 Frequency Reuse Feed

7. Electronics equipment shelters.

   Earth station electronics can be factory installed in portable buildings to minimize on-site installation time and expense. These shelters are common for transmitting and receiving earth stations since the high power amplifiers must be located within a short waveguide run to the antenna feed. These buildings, which are available in many sizes, are completely wired, lighted, air conditioned, and heated prior to shipment to the installation site.



Earth Station Equipment Building.




Typical Transmitting/Receiving Earth Station Equipment Layout

# HOW TO PLAN AN EARTH STATION PROJECT

H. Michael Smith
Manager - Earth Stations
Cable Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**How to Plan an Earth Station Project**

Webster defines a plan as a scheme or program for making, doing, or arranging something. A formal written plan is definitely in order when attempting to install an earth station. This is necessary to ensure that all tasks are accomplished and in the most effective manner. This will result in identifying those tasks that can be done in parallel and those that must follow sequentially. The proper planning job will allow accurate project cost determination as well as time estimates for project completion so that business objectives can be met. Items to be addressed herein are those necessary for the planning process as well as general identification of all tasks that must be performed as part of an earth station project. For simplicity, video receive-only stations will be discussed; however, the basic project tasks remain essentially the same for earth stations to be used for other purposes.

The first step in any project is to precisely determine the business purpose of the project. There are many questions to be answered, such as:

1. Will the station be used for video, message, or data service?
2. Will the station be receive-only or receive/transmit?
3. Are the current plans valid for the foreseeable future, or do future equipment applications need to be planned for now?
4. For cable television video, is pay television being added? Are other non-premium services being added? Perhaps both? At the same time? Is a rate increase to be tied to the addition of satellite-delivered signals?

The answers to these questions will be a major factor in determining technical requirements and establishing the equipment configurations. With a firm goal in mind, you are ready to proceed with identifying and accomplishing the following tasks.

**Select a Site**

Site selection is discussed in detail in a later paper from a technical acceptability standpoint. Naturally, a key point in picking a site is finding the required amount of space in a location convenient to the rest of one's operation. Generally, several sites are tentatively selected and then checked for frequency coordination, availability for purchase or lease, proximity to other facilities, accessibility, etc. Site selection is a local function done primarily by the earth station owner/operator with suitability confirmed by the frequency coordination process.

**Frequency-Coordinate that Site**

This also is covered elsewhere. The purpose here is to list all steps in the project and to describe how they are accomplished and how they are interrelated. Frequency coordination is an outside service that is purchased by the owner of the proposed station. The process consists of computer analysis of a data base containing terrestrial microwave paths and many times an on-site RF measurement is also required before a site is cleared as suitable for filing and operation.

**Decide on Performance Standards**

At some time early in the project a technical/economic decision must be made concerning the level of technical performance that must be met by the station. Even though there are many parameters that describe operation of the earth station and its components, carrier-to-noise (C/N) and signal-to-noise (S/N) are the bottom line parameters most often considered for CATV video receive-only stations. Besides achieving carrier-to-noise ratios that are licensable by the FCC, the cable operator strives for carrier-to-noise and signal-to-noise figures that will ensure his subscribers of a quality picture free of thermal noise and impulse noise.

**Configure the Earth Station**

All of the preceding considerations have an effect on what equipment will be used in the earth station. These decisions are made either with or without the help of an equipment manufacturer or frequency coordinator. Equipment decisions to be made are:

1. Antenna size.
2. LNA gain and noise temperature.
3. Length and size of coax between LNA and receiver.
4. For video applications, number of receivers needed as well as choosing between types of frequency selection - crystal change versus frequency agility.
5. Automatic failure protection of LNA and/or video receivers.
6. Any other interface electronics, such as RF modulator for CATV or broadcast applications.
7. This is a good time to be thinking about test equipment needed for maintaining the station.

**File for Construction Permit (CP) and License**

Licensing procedures are covered separately.

**Procure Equipment**

In general, this is done at about the same time as submitting the application for a CP. There is no prohibition against accepting delivery of equipment prior to receipt of a CP. The only restriction is that no site preparation can start until the construction permit has been issued.

**Receive Construction Permit**

This very necessary step is now fairly routine for video receive-only applications. Due to staff additions and computer techniques, the processing time at the FCC has been cut drastically within the past six months.

**Build the Earth Station**

Major parts of the actual construction are:

1. Install the foundation for the antenna.
2. Provide space for and install indoor electronics such as receivers, pressurization system, etc.
3. Erect antenna and mount on foundation.
4. Install RF and power cables between LNA (at the antenna) and indoor receive equipment.
5. Mount the LNA and make RF and power connections.
6. Activate the equipment.
7. Point antenna at satellite and peak for optimum operation.
8. Verify compliance with previously set performance standards by electronic testing.

# FREQUENCY COORDINATION OF AN EARTH STATION

Harry L. Stemple, PE
Comsearch, Inc.

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## FREQUENCY COORDINATION OF AN EARTH STATION

### Introduction

Over the last year and a half since the FCC decision on small diameter earth stations, prospective users have heard a lot about frequency coordination as the first step to establishing a receive-only or transmitting and receiving earth station. Now that TVRO's for cable systems are more commonplace, the time has come to give more details about frequency coordination, how it is accomplished and the effect of changing earth station parameters on its interference susceptability.

Frequency coordination is a catch-all phase which encompasses multiple tasks required prior to filing an FCC application for an earth station. These include site selection, interference analysis, coordination data preparation, data circularization, interference objection clean-up, and filing report preparation.

This article concentrates on two of the tasks listed above — interference analysis, coordination data preparation, and the factors influencing the results. The various parameters which influence frequency coordination will be discussed as well as the effect of changing these factors to reduce interference potential.

### Interference Objectives

Before an interference analysis can begin, the interference objectives, i.e., the maximum allowable interference signal power, must be established. For video systems, the basic problem in this area is in relating the subjective measures of interference (viewing quality) to engineering terms (carrier-to-interference ratio or interfering signal level). This is typically done by viewer juries where various levels of interference are created under controlled situations and the viewers indicate at what magnitude of interference the picture is degraded. Many tests such as these have been conducted with basically the same results.

Although the modulation of the interfereing signal affects the relationship between the subjective interference situation and the equivalent objective measure, the tests have shown that for the range of modulations normally encountered in the 4 GHz band, the interference threshold varies only a few dB among the types. The frequencies used by terrestrial carriers in the 4 GHz band are highly standardized, each being offset 10 MHz from the centers of the satellite transponders. Given this frequency separation and the types of modulation predominately used, the interference to the earth station appears as an increase in thermal noise at the output of the discriminator. In summary, for a normal video receiving situation, interference is relatively insensitive to the interfering signal modulation characteristics normally encountered.

At a C/I ratio of 15 dB the interference becomes barely discernible on a waveform monitor and at about 12 dB it becomes visible on a TV monitor. The degradation of the picture quality occurs very quickly as the C/I ratio approaches the FM threshold level of the earth station receiver. This is logical since the interference adds to the thermal noise and produces an overall C/N lower than the C/I. For standard receivers this level is about 10 dB and down

to about 7 dB for threshold extension receivers. At these C/I levels the picture degradation becomes objectionable. Prior to this level of interference there is a steady decrease in signal-to-noise ratio as the C/I decreases just as if the C/N decreased, but was still above threshold. To provide a safety margin, the earth station is coordinated to insure a C/I in excess of 25 dB at least 80% of the time and 15 dB at least 99.99% of the time.

One should keep firmly in mind that these are objectives, not strict cut-off values. Recall that at a C/I of 25 dB there is no perceptable interference, and at 15 dB the interference is barely visable on the waveform monitor.

The traditional unit for interference in satellite earth station analysis is absolute received power levels rather than C/I objective. Therefore, to set the interference power level objectives for an earth station, one calculates the nominal signal power received from the satellite and reduces that value by the C/I objective.

For data or message systems, the interference objectives may be set by using the methods described in the FCC Rules 25.252. This method results in interference objectives relative to the earth station system noise in a reference bandwidth.

For broadband satellite systems, (e.g., multi channel message systems) the objectives would apply to the full carrier interference level if the bandwidth included the interfering signal center frequency. For narrow band systems. (Single channel per charrier, or 56KBps data streams, etc.) the objective is derived from the FCC Rules as a starting point. If compared to the full carrier power of the interfering signal, the objective can be reduced by the spectral power of the interfering signal in the reference bandwidth relative to the unmodulated carrier. Figure 1 shows a typical interference reduction factor graph for interference from a 1500 channel FDM-FM system for a receiving system with a 45 kHz noise bandwidth.

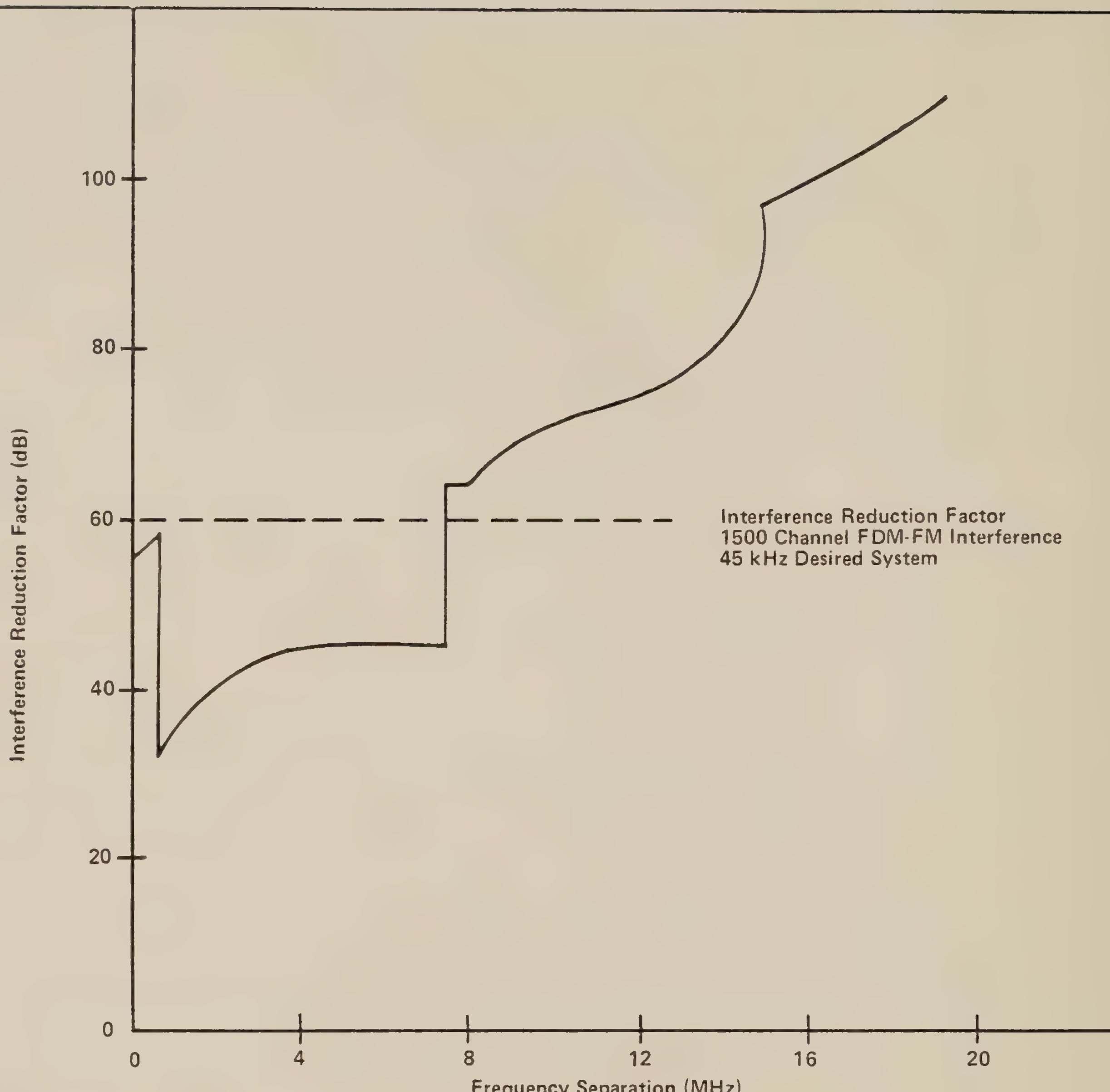



Figure 1. Downlink Interference Reduction Factor

Similarly, some frequency offset advantage is available for interference into terrestrial systems from narrow band transmit earth stations. Here the interference reduction factors are not derived so easily. The FCC Rules give the objectives for interference into 6 GHz systems as −154 dBW/4 kHz (20%) and −131 dBW/4 kHz (0.01%). The method commonly used to adjust these values for frequency offset is to mathematically convolve the satellite signal spectrum with the desired signal spectrum. The correction factor is then the difference between the maximum result of the convolution and the value at the frequency separation of interest. Figure 2 illustrates this. Another method would be to determine the C/I ratio which would result in no more than a specified level of noise added to the desired signal. A typical value would be 5 pWp0 of added interference noise.

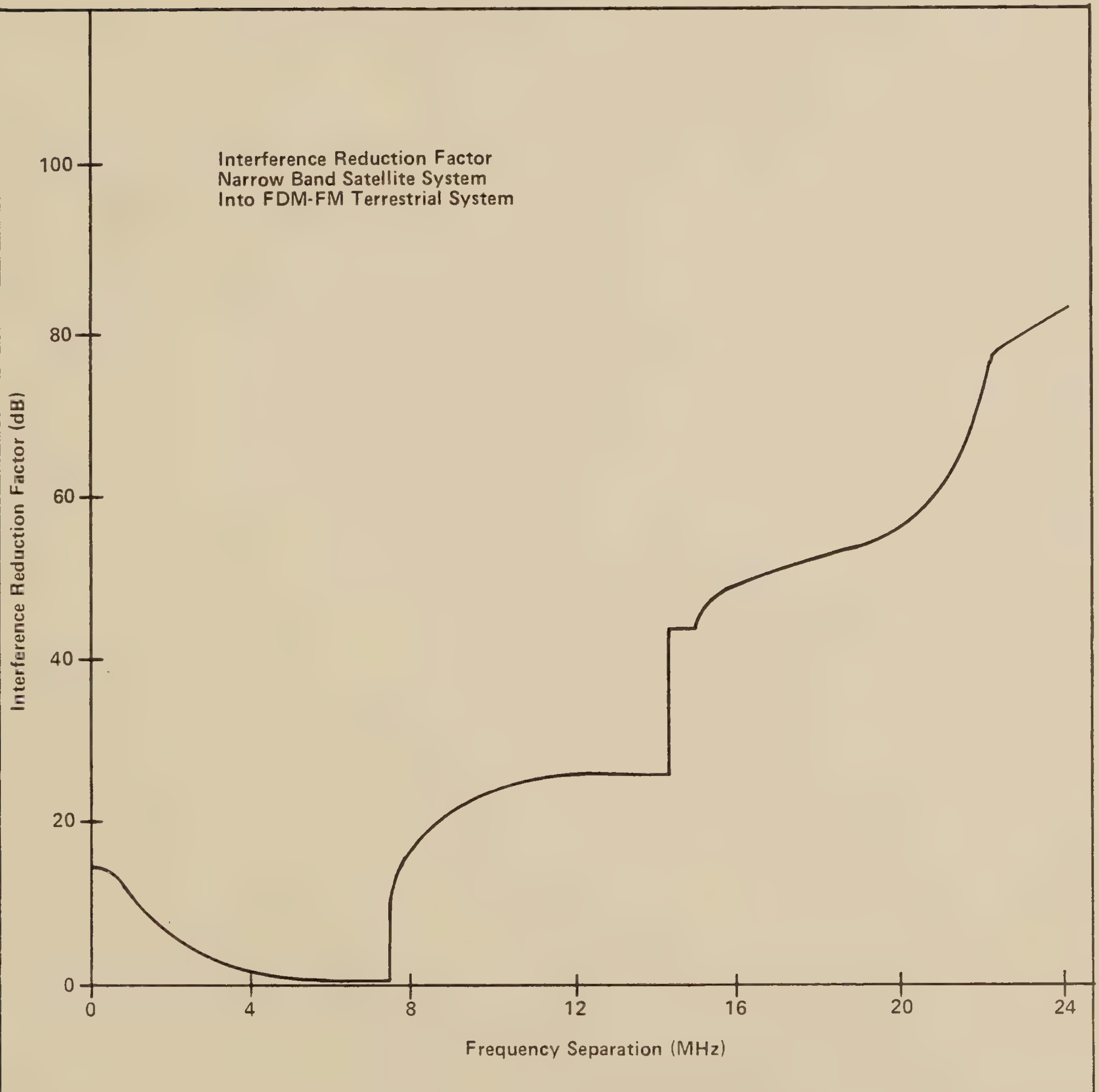



Figure 2. Uplink Interference Reduction Factor

**Interference Factors** Once an interference objective has been established, the received signal levels for each potential interference case can be computed and compared to those objectives. The major factors affecting the transfer function from the interfering transmitter to the victim receiver are the antenna systems and the propagation path.

An ideal microwave antenna would radiate all its energy in a narrow beam with none escaping in any other direction. In practical antenna systems, most of the energy is in the main beam, but significant levels of radiation are emitted (or accepted) at angles off the main beam. The angle at which one considers this radiation is called the discrimination angle, and the level of radiation relative to the main beam is termed the antenna discrimination. This effect is applicable to both the earth station and terrestrial station antennas. A typical antenna radiation pattern is shown as Figure 3.

Propagation loss between the interference source and the victim receiver has a great effect on the levels received. For line-of-sight conditions or unobstructed paths, free space loss calculations are used. The separation distance is the factor of importance and the loss increases as the square of the distance for free space loss.

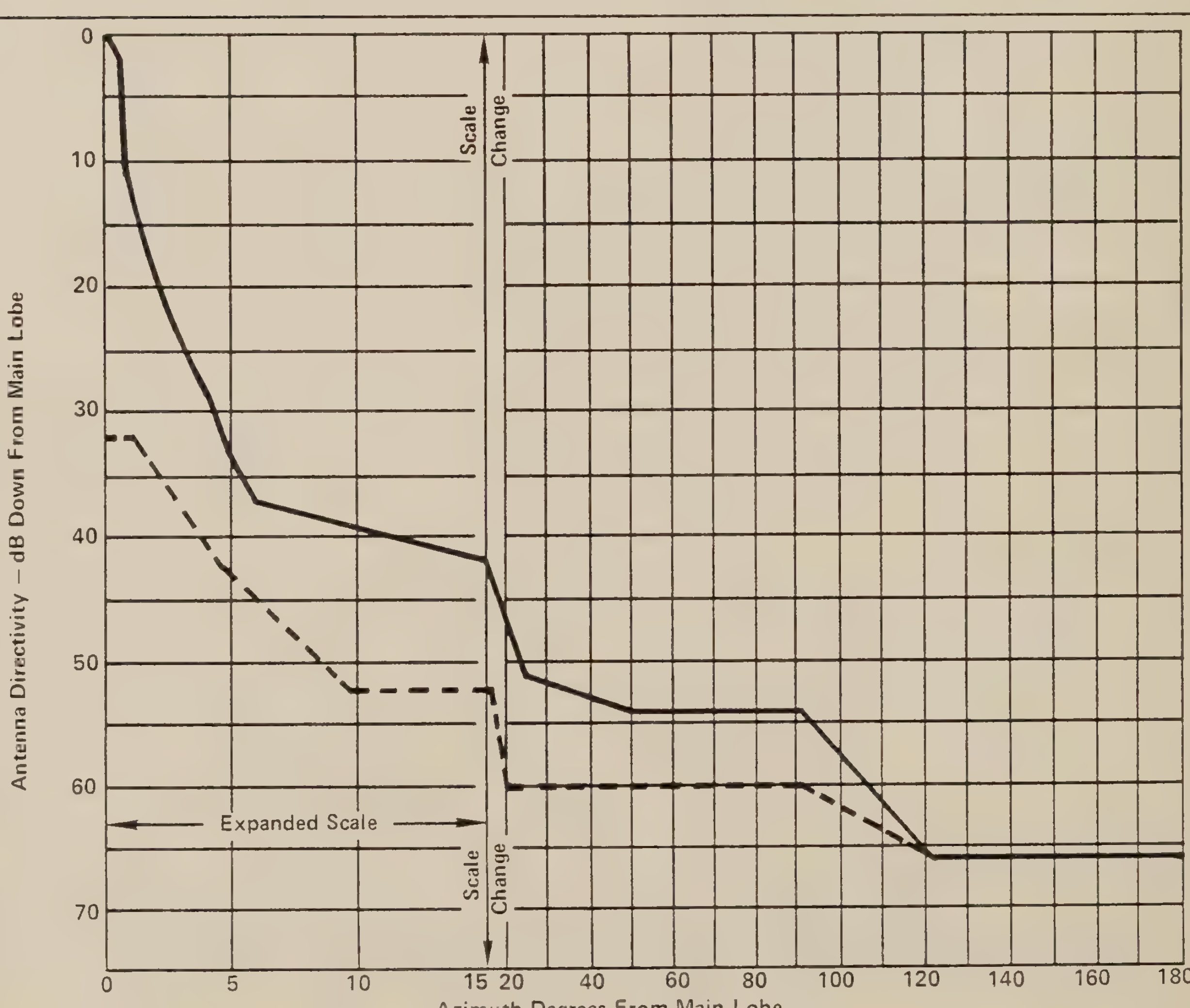



Figure 3. Typical Antenna Radiation Pattern Envelope

Local earth station site shielding has a substantial effect on the loss with more distant obstacles contributing as well. For obstructed paths, separation distance still affects the loss by the same relationship, but the terrain features add to the loss. Generally on short obstructed paths, the interference propagates by the diffraction mode with the interference bending over the blockage. On paths with a single obstacle the amount of loss realized is dependent on the percentage of blocking of the first Fresnel zone radius and on the character of the obstacle. Rounded obstacles produce significantly more loss than knife-edge blocking.

For longer interference paths the earth station and the interference source see different horizon points and generally forward scatter of the signal from the troposphere is the predominant effect. In this case the factor which influences the loss is the angular separation of the terrestrial and earth stations. The angular distance is composed of a simple distance component plus additions for the horizon elevation angles. Large median losses relative to free space are possible for this propagation mode, but it is subject to wide variation with time. For short periods of time under certain atmospheric conditions, much of the loss diminishes and the isolation can near that of free space.

The detailed relationship between the propagation loss and the characteristics of an obstructed path are beyond the scope of this paper. However, one could assume that shielding close to the earth station is the most effective since it can influence the horizon elevation angle more readily and thus increases the loss. Changing the antenna centerline relative to the surrounding terrain can have a great effect on loss as well.

## Horizon Gain Function

Interfering signals received by earth stations are strongest at the horizon and decrease for elevated angles above the horizon. If the interfering signal levels decrease faster with elevation angle than the increase in antenna gain (as is typically the case) the interference from the horizon will contribute the most noise. This is why antenna gain toward the horizon is used.

Calculating the horizon antenna gain for the terrestrial microwave stations in the direction of the earth station is a straight forward procedure since these are oriented at a nearly zero elevation angle. One simply determines the discrimination angle for the terrestrial station and obtains the discrimination value from the appropriate ratiation pattern envelope. The antenna gain is then the difference between the main beam gain and the discrimination.

Calculating the earth station horizon antenna gain in the direction of the terrestrial station is not quite as simple. To do this, one must consider that the earth station antenna can be oriented to view an arc of satellites, it is not directed horizontally, and very often the horizon it sees is elevated. The earth station horizon gain for the interference calculations is a gain curve such as shown in Figure 4. This graph gives the earth station antenna gain toward the horizon as a function of azimuth. It considers the various pointing angles of the antenna, and its radiation pattern envelope. After the plot has been developed, one determines the bearing from the earth station to the terrestrial station, enters the curve at the azimuth and reads the value of gain to be used for the interfence calculations. Clearly, if the antenna location is changed, the horizon profile is modified and this is reflected in a new horizon gain function. Obviously, a change to an antenna with a different radiation pattern changes the horizon gain also.

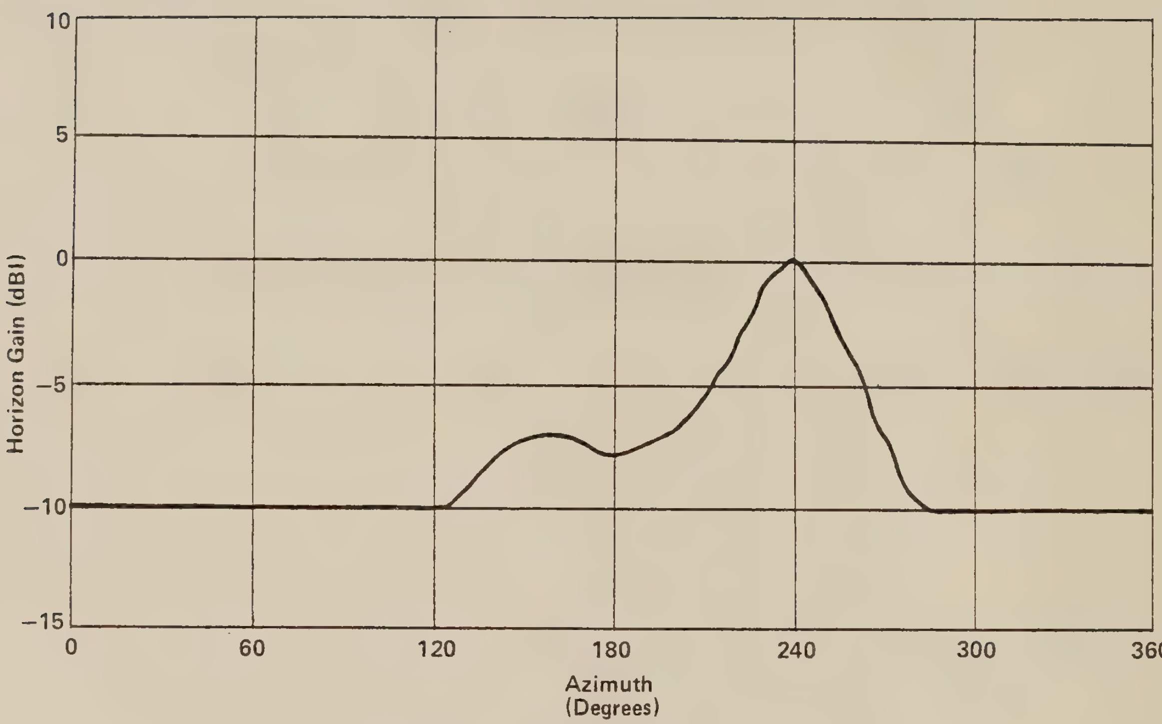
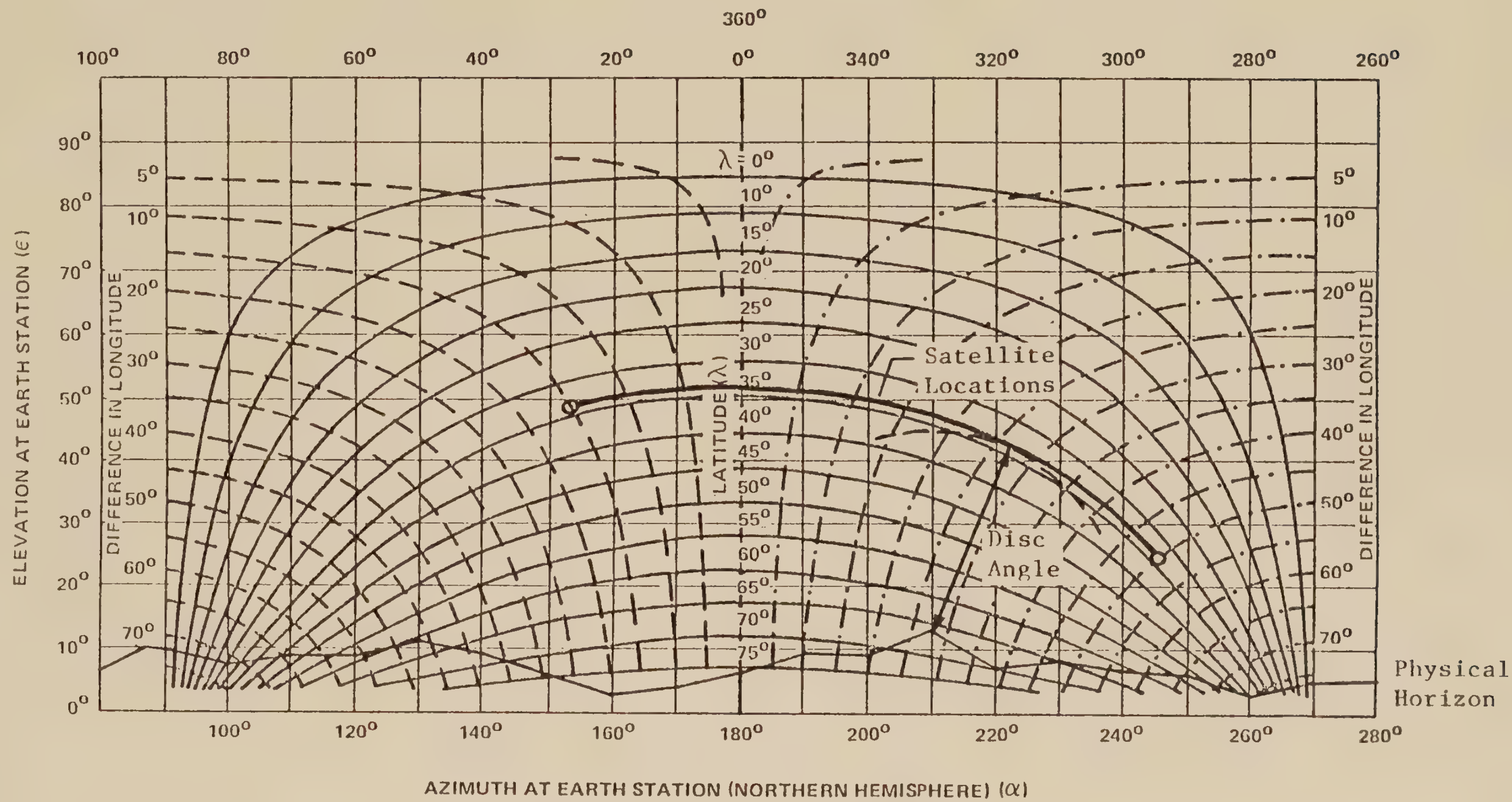



**Figure 4. Typical Horizon Gain Curve**

Figure 5 illustrates how the earth station horizon gain plot can be derived graphically. The computerized method of determining horizon gain is adapted directly from this technique and analytical expressions are used to determine the satellite position.

The curved solid lines show the arc of the geostationary orbit visible from the earth station at latitude $\lambda$ and the longitude difference between the satellite and the earth station. The heavy solid line in Figure 5 shows the locations of satellites from 70 to 136 degrees west longitude as they would appear in the sky for an earth station near Atlanta. Toward the bottom of the graph, the horizon elevation as viewed from the earth station is depicted. For any particular azimuth, the earth station discrimination angle is defined as the smallest angle between that point on the horizon and the geostationary arc. Figure 5 shows an example for an azimuth of 210 degrees, where the angles between the horizon and the closest approach of the arc is 32 degrees. This is the earth station discrimination angle to be used for 210 degrees. Now that the angle has been determined, the gain can be read from the earth station radiation pattern envelope. This process continues for the full 360 degrees to generate a complete horizon gain plot. From the graphical presentation it is easily seen how an increase in horizon elevation decreases the discrimination angle.

# POSITION ARCS OF GEOSTATIONARY SATELLITES




ARC OF GEOSTATIONARY SATELLITE ORBIT VISIBLE FROM EARTH STATION AT TERRESTRIAL LATITUDE λ
DIFFERENCE IN LONGITUDE BETWEEN EARTH STATION AND THE SUB-SATELLITE POINT:

SATELLITE LONGITUDE E OF EARTH STATION LONGITUDE
SATELLITE LONGITUDE W OF EARTH STATION LONGITUDE
SATELLITE LONGITUDE EQUAL TO THE EARTH STATION LONGITUDE

Figure 5. Graphical Derivation of Horizon Gain Curve

**Received Signal Level Calculations**

The relationship between the factors discussed above and the received interfering signal level is given by:

$$P_r = P_t + G_t - L + G_r \qquad (1)$$

where

$P_r$ = received signal level (dBW)

$G_t$ = gain of the transmit antenna toward the earth station (dB)

$L$ = basic transmission loss (dB)

$G_r$ = gain of the earth station toward the transmitter (dB)

Equation 1 applies to interference propagated via great circle mechanisms as differentiated from the precipitation scatter mode of interference.

**Coordination Contours**

Great circle coordination contours are another required showing of a frequency coordination package. Now that sufficient background information has been developed, the contours can be discussed. The purpose of the coordination contour is to define an area outside of which the potential for interference is so remote that stations beyond this limit need not be considered. The procedure is to establish the amount of loss required to reduce the interfering signal levels below the objective and relate the loss to a distance. The basic relation for the loss required is obtained by solving equation 1 for L.

$$L_{req} = P_t + G_t + G_r - P_o - H \qquad (2)$$

where

$L_{req}$ = loss required to meet objective (dB)

$P_o$ = interference objective (dBW)

$H$ = correction factor for earth station horizon (dB) with other terms as previously defined.

To obtain the loss required, one must make some worst case assumptions. For the worst case one would assume that the terrestrial station is aimed directly at the earth station. Therefore, maximum values for $P_t$ and $G_t$ are used with no antenna discrimination for the terrestrial systems. From equation 2 the two effects on the coordination contours due to different antennas can be seen. First there is the interference objective $P_o$ which is directly affected by changes in antenna mainbeam gain. Also, there is $G_r$, the horizon gain function, which in previous paragraphs has been shown to be affected by antenna characteristics.

The FCC rules prescribe the ralationship between loss required and distance. The relationships are valid for distances of 100 km or more and are approximately a 80 log distance curve as compared to the 20 log distance slope for free space propagation. A typical coordination contour is shown in Figure 6.

If the horizon for an earth station is less than 0.2 degrees, the horizon correction factor H is zero and the coordination contour will be smooth with an elongation toward the southwest, southeast, or both depending on the earth station location. This elongation is a result of the lower satellite elevations which increase the earth station horizon gain in those directions.

The coordination distances are very sensitive to horizon elevation angles if greater than 0.2 degrees. The jagged nature of the contour shown in Figure 4 is due to the horizon effects. The correction factor H of equation 2 is also specified by FCC rules and is a function of loss required as well as the horizon angle.

### Precipitation Scatter Interference

Precipitation scatter interference results if the beam of the earth station intersects with the terrestrial station beam and if precipitation in the common volume formed by the intersection is sufficiently heavy to scatter the transmitted signal into the receive antenna. The factors which influence the magnitude of the interference are the geometry (how nearly do the centers of the two beams intersect) and the efficiency of the scattering (which is dependent on the rain rate). Once again the angular separation of the beams is used to obtain the terrestrial station antenna gain; the greater the angle, the less potential for interference. The present model used in determining the interference power received through this mechanism assumes that the terrestrial antenna gain is constant across the common volume. If the terrestrial station is close to the common volume or the discrimination angle is small, this may not be the case. By adding an extra integration function the precipitation scatter routines, this can be considered. Fortunately, the present method gives conservative results under these conditions. The precipitation scatter coordination contour is interpreted the same as the great circle contour: stations beyond the contour need not be considered.

Although there can be a great number of beam intersections between terrestrial systems and the earth stations, it is interesting to note that the only beam intersections which offer potential interference problems have a correspondingly bad great circle case. Unlike great circle interference where shielding can clear the case, the type of site shielding which is normally encountered is ineffectual on precipitation scatter cases. This is because the scattering volume is elevated and can be as high as 15 km above the earth station. Little can be done to clear a precipitation scatter case except to relocate the earth station.

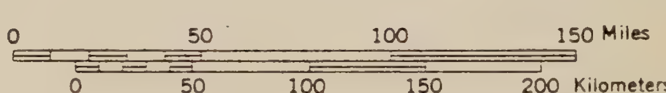
Fortunately, there is not always a correspondence between bad great circle interference cases and precipitation scatter cases, otherwise the site selection process would be much more difficult.

### Effect of Small Diameter Dishes on Frequency Coordination

The first characteristic of the small diameter dish to be considered is the reduction in main beam gain. This reduces the received level from the satellite and requires a dB for dB tightening of the interference objectives. As compared to a 10 meter system, the interference objectives for the same location with a 5 meter antenna are 6 dB more stringent.

A reduction in antenna diameter also bring a broadening of the beamwidth. As long as the beam does not get so broad that adjacent satellite interference becomes a problem, the wider beamwidth does not affect the terrestrial interference situation. It is the sidelobes beyond 25 degrees which are most important for coordinating with terrestrial systems.

An interference advantage of the small dish is its lower centerline. This makes it more easily shielded by the natural terrain and yields greater horizon angles which in turn result in higher propagation loss. Artificial shielding of the small dish is obviously easier.


Comsearch, inc.

2936 Chain Bridge Road • Oakton, Virginia 22124 • (703) 281-5550

Figure 6. Typical Coordination Contours.

# SATELLITE EARTH STATION FREQUENCY COORDINATION

Harry L. Stemple, PE
Comsearch, Inc.

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Benefits of Frequency Coordination of Satellite Earth Stations**

*Frequency coordination of satellite earth stations is beneficial to the applicant for a number of reasons. Because domestic satellite systems share the 4 and 6 GHz band, predominantly used by terrestrial common carrier systems, each must consider the others facilities during system planning so that mutual interference may be minimized. The process of exchanging technical data relevant to interference and the resolution of potential interference conflicts prior to filing an application with the FCC is known as frequency coordination. With over 10,000 microwave paths in the United States and hundreds of carriers with which to coordinate usage, this task is considerable.*

*Obviously, the main reason for frequency coordination is to determine whether or not the earth station will perform satisfactorily in the microwave environment. In the case of transmitting earth stations, one must ensure that it will not cause harmful interference to the terrestrial operator as well. The need for these studies to make this determination is rarely questioned. But the requirement to exchange plans with other carriers and to seek an FCC license, if one is proposing a receive only earth station, often is.*

*From an earth station operator's point of view, possibly the best reason for coordination and licensing is the formal recognition of his facility. Once you coordinate your earth station all terrestrial carriers must subsequently coordinate with you when they plan new or modified 4 GHz routes. This protects you against future interference before the fact. This is why a terrestrial user who can only cause interference to a receive only earth station wants to be sure no conflicts exist as a result of the initial coordination. If there were unresolved problems, the earth station operator would have a veto power over the terrestrial carrier's growth plans.*

*While you wait for the thirty day coordination period to expire you may not think this procedure speeds the processing of your application, but it does. Invariably, potential interference cases will be cited during the coordination period which must be resolved. Usually the cases reported are no surprise but the dialogue to demonstrate that there is no interference potential and agreement to accept the degradation, if any, must be completed. The prior coordination process provides a convenient vehicle to discuss these problems at an engineering level. This can be accomplished by exchanging letters between the coordination agent and the carrier involved. Sometimes a phone call will suffice.*

*It was not always this easy. In the days before prior coordination, potential interference problems were not identified until after filing. The affected carrier's first action would be to file a petition to deny the application. The application would not be freed for processing until the applicant filed his response to the petition and the objections were withdrawn. Everything was handled quite formally with the exchange of correspondence being made by lawyers. This process could drag on for months.*

*Another benefit from frequency coordination is a second opinion on the electromagnetic compatibility of your earth station. Each carrier who uses 4 GHz microwave will analyze the proposed earth station with respect to his data base and report any cases of potential interference. Terrestrial carrier is usually more pessimistic than your frequency coordinator and reports all cases as if they were line-of-sight. This gives your coordinator an opportunity to question any significant differences in results and to re-examine the terrain blockage profile as he responds to the objections.*

*Finally, a receive only earth station really can affect other users, not from interference with terrestrial systems but by its possible influence on future space segments. After all, the receive only earth station is part of a larger communications system. Two aspects of space system design which immediately come to mind are satellite spacing and orbital longitude. The geostationary arc is a limited resource, and the FCC is dedicated to its conservation. Earth station antenna characteristics are one factor which influences satellite spacing. Coordination and licensing of receive only earth stations allows the FCC to control this parameter.*

*There are only six U.S. domestic satellites in place and apparently the FCC views their location assignments as another variable to be used in maximizing orbital utility. In this regard, the FCC requires earth station applicants to coordinate their earth station for the full geostationary arc in the event the FCC may choose to move satellites around in space.*

*We have seen that frequency coordination and licensing of earth stations brings formal acknowledgement to them and provides protection for them against future interference by a mechanism which detects interference before the fact. At the same time it speeds the processing of the application at the FCC since all interference conflicts are resolved before the filing. In view of these reasons, frequency coordination should be considered a benefit rather than a burden imposed by the FCC.*

## Extended Interference Analysis of Satellite Earth Stations

### Introduction

*One of the first things a prospective earth station operator does in pursuit of an application is to order a frequency coordination study. The normal procedure for the interference analysis of a potential earth station site involves access to a computerized data base of terrestrial microwave systems, using a computational procedure outlined by FCC rules, and extracting data from topographic maps to consider effects of terrain shielding. In many instances analysis of this extent is sufficient to demonstrate that the earth station is compatible with the microwave environment. It is generally accepted that the procedures used in office studies are conservative, as well they should be, because of the many unknown parameters which come into play.*

*If the office study shows the earth station will clear, it will be good with a high degree of confidence. If the office study shows the location to be subject to severe interference, degradation of performance is to be expected. For those sites which are shown to fail or just meet the interference standards by a modest amount, further refining of the analysis may be in order.*

*There are two interference mechanisms which are considered in evaluating a potential earth station site. These are great circle and precipitation scatter. Great circle interference is that type of interference which follows a near great circle path between the earth station and the terrestrial relay. The modes of propagation are varied, but are mainly diffraction over path obstacles or forward scattering of energy from the troposphere. Precipitation scatter interference does not necessarily follow a great circle path but occurs as a result of energy scattering from rain drops.*

*The extended analysis discussed in this paper is confined to defining and correcting the great circle interference cases only since little can be done to mitigate precipitation scatter cases except site relocation.*

*Depending on the prospective earth station operators situation, he may be justified in abandoning his initial site in favor of another. Your frequency coordination agent will usually help you select and coordinate new sites, for the same basic fee. For others, a more detailed analysis to better define the magnitude of the problem so that the viability of corrective measures may be evaluated more intelligently may be in order.*

### Extended Analysis

*To further refine the office study some analysis beyond which is normally done is required. Extended analysis most often means on-site field work either by the prospective earth station operator or by consultants.*

**Local Shielding**

*One of the first improvements in the office study which can be made is to provide better input for the propagation loss prediction routines. Normally input data is taken from USGS topographic maps. This provides terrain heights along the path, but there are many other obstacles which could be present that would offer additional isolation between the earth station and the terrestrial microwave tower. Buildings and dense groves of trees are the types of obstruction which are normally considered as better path definition.*

*Slight antenna relocation can provide improved electromagnetic compatibility. With potential interference problems identified the final position of the earth station antenna can be chosen to take maximum advantage of near-in obstacles along the azimuth where the interference is expected.*

**Field Intensity Measurements**

*RFI measurements have proven themselves very valuable in determining more precisely the extent of an interference problem predicted by the office study. The results of the measurements normally show the interference problems to be less severe than predicted, but occasionally point out unpredictable problems such as reflections.*

*The RFI measurements quantify the interfering signal levels arriving at the site. At 4 GHz, the earth station receive band, the measurements give a direct evaluation of expected interfering signal levels. At 6 GHz, the earth station transmit band, the levels measured at the earth station site are used to compute the isolation between it and the terrestrial receiver. From the isolation, the expected interference level at the terrestrial receiver can be predicted.*

*Figure 1 shows a typical measurement block diagram. This configuration uses an 18-inch broadband test antenna, the output of which goes to a low noise amplifier which establishes the maximum measurement system sensitivity. A spectrum analyzer is used as a detector and photographs of its display provide a record of the measurements.*

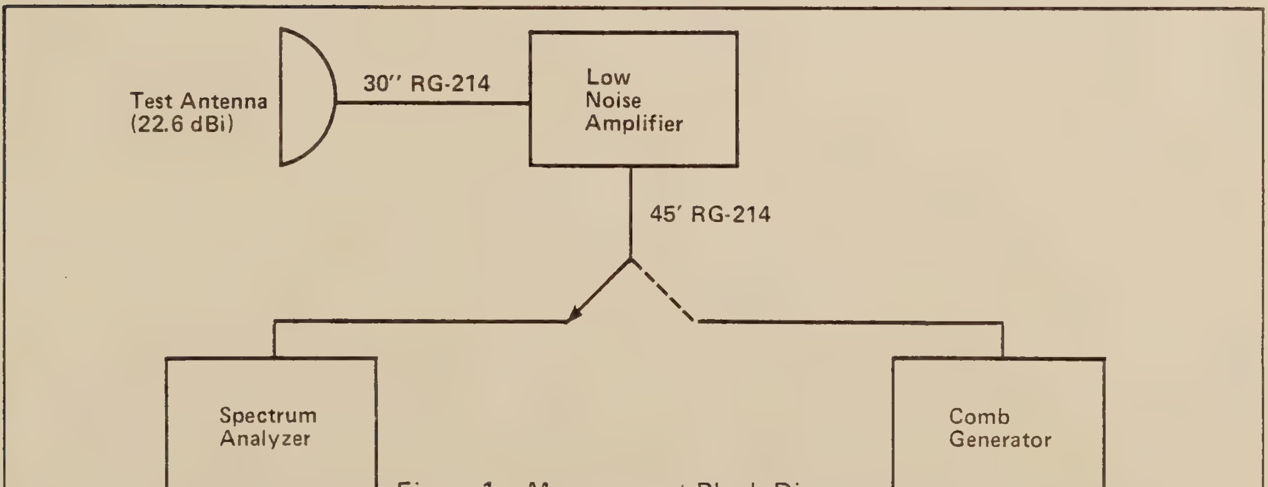



Figure 1. Measurement Block Diagram

*Normally, the sweep width of the spectrum analyzer is set to display the full 500 MHz of either the 4 GHz or 6 GHz common carrier bands. The test antenna is scanned 360° to detect any interference sources with scans being made for both vertical and horizontal polarizations. Figure 2 shows a spectrum analyzer display photograph with several terrestrial microwave signals.*

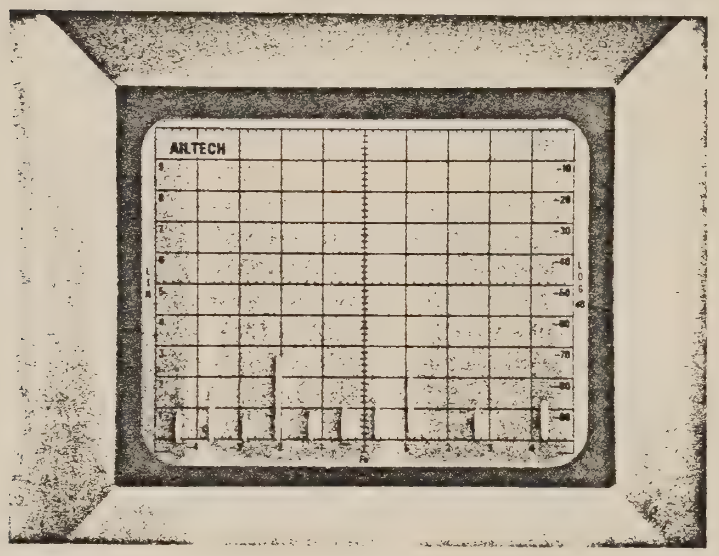



Figure 2. Spectrum Analyzer Display

*Over a 24-hour period, the best microwave propagation conditions and thus the worst interference situation occur after midnight and continue until sunrise when air temperature begins to increase. Typically measurements are made during the daytime to allow for easy set-up and a preliminary look at the site. The tests are then repeated at night to get a feel for the fluctuation which might be expected. Using statistical information from the propagation loss prediction models, one can extend the results of the measurements to the worst season of the year and short term levels of interference.*

**Diffraction Screens**

*Diffraction fences constructed of expanded metal or chain link fence with metal strips inserted in the mesh could be used to reduce interfering signal levels. The analytical methods for computing the loss due to a diffraction fence are from classical optics model for knife-edge diffraction. This method supposes that the knife-edge is in the far field of the earth station antenna (1.5 miles at 4 GHz and 2.2 miles at 6 GHz). A fence constructed at these distances would be very large and add an additional land acquisition problem. To achieve 15 dB of shielding at 1.5 miles from the earth station the screen should extend 37 feet above the antenna centerline and be about 200 feet wide. One should not rely on diffraction fences for large amounts of isolation if they are constructed too close to the antenna. Losses of 20 dB are maximum and 15 dB is a comfortable value. Little empirical work has been done concerning diffraction fences in the near field. Further studies could instill greater confidence that larger losses could be achieved. Also, erection of any useful diffraction fences (say 40 x 60 feet) will require careful consideration of structural factors.*

*Since the diffraction fences are usually proposed to be constructed within the near field of the antenna, it is difficult to separate the effects of shield and antenna. For rigorous analysis, the shield would be considered part of the antenna for calculation of its far field gain.*

**Pit Shielding**

*Pit shielding, i.e., erection of earthen mounds around the earth station have been shown to provide more than 25 dB of shielding. The earth station site must be large enough to accomodate the pits sloping sides and one must consider the significant drainage problems if the antenna is completely surrounded by the pit. A pit large enough to hold a 10 meter antenna and allows full clearance of the geostationary arc could occupy a 200 x 270 feet area.*

*A pit designed as suggested by Lucia of COMSAT for a satellite earth station is in the middle Atlantic States to view the full geostationary arc from 70° to 135° west longitude is shown in Figure 3. Given the pit design, if one uses the knife edge equation to compute the loss where the shielding is least, the shielding is predicted as 21 dB. This compares favorably with the measurements performed by COMSAT.*

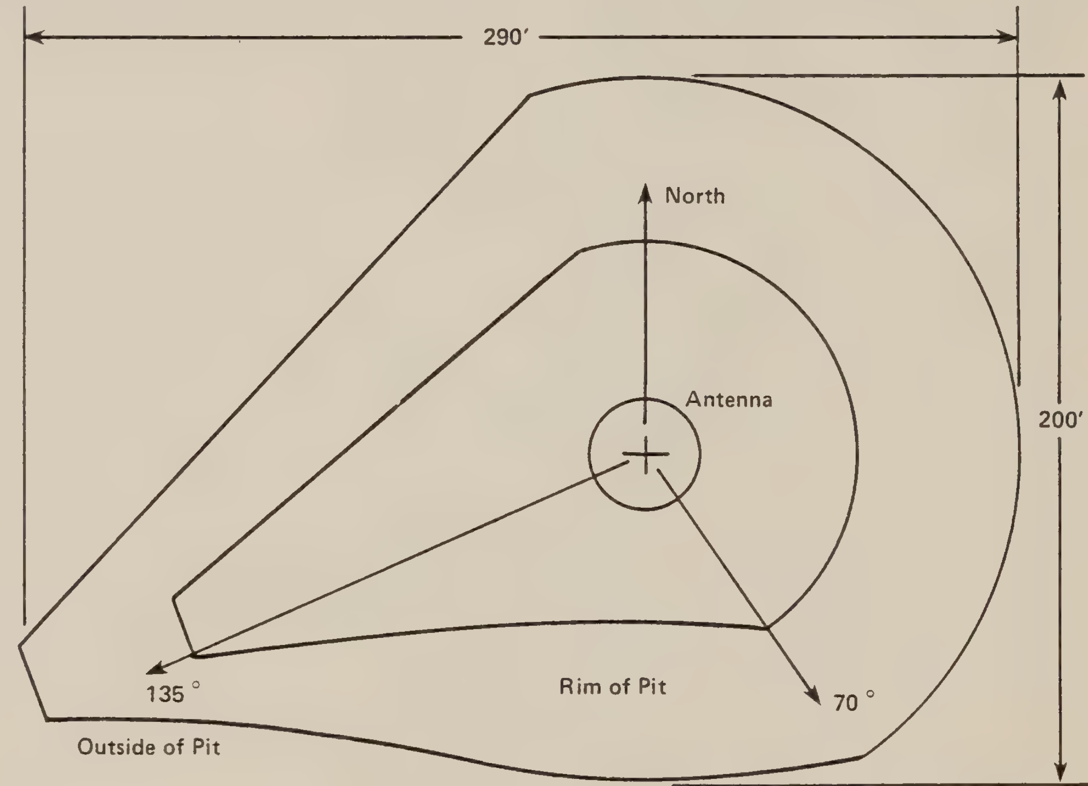



Figure 3. Typical Pit Shield Design

**High Performance Antennas**

*High performance earth station antennas are another approach to reducing interference. These are not mass produced and can be quite expensive. Comparison of the vendor's antenna pattern with the FCC reference curve may show some improvement and this may be used to advantage in frequency coordination.*

**Interference Cancellers**

*Interference cancellers, devices used by the military and in simpler forms by CATV operators to reject unwanted TV signals, is another possible remedy for interference problems.*

*These devices obtain a replica of the interfering signal, invert it, adjust its phase and amplitude, and then add it to the antenna output which effectively cancels the unwanted signal. Cost of such a device would be S10,000 to S25,000 per interference source direction.*

**Summary**

*To summarize, office studies can usually clear a site, but either corrective measures such as relocating, shielding, cancellers, or measurements to show there are no problems may save on aparently unacceptable locations.*

**Basic Site Requirements**

*Until the last year with the explosion of receive only earth stations for pay TV, earth stations sites were carefully selected with protection from interference the primary consideration. Most locations were many miles from the cities which they were serving with the ideal earth station site being naturally shielded by terrain and at a spot which was calculated to be virtually free of interfering signals. For most types of communication, this type of isolation is not required although it is still true that shielding makes the site.*

*Before making a detailed interference study you can get a pretty good idea of how the location you have in mind will coordinate.*

*Can you see any microwave towers from your site? If you are that close, there is a high probability of unresolvable interference problems. If you have a choice of a location high on a hill or down in a valley, take the valley. A site surrounded with dense trees can be good for reducing interference levels into the earth station, but if you are planning up link capability they may be of limited help in coordinating with the 6 GHz users. If you have a downtown location, you should plan on RFI measurements. Reflections from the large flat surfaces of office buildings can be devastating if there were some very bad cases of potential interference predicted.*

*How much interference can an earth station tolerate? Typically the carrier-to-noise (C/N) ratio at the earth station receiver input is about 13 dB. Since the effect of interference is nearly equivalent to lowering the C/N by adding to the noise, we can get some idea of the levels of interference which can be tolerated.*

*If one chooses the long term interference objective to be 1 dB degradation to the C/N, then the maximum allowable interference level for a single entry of interference would be 6 dB below the system noise. If one were to allow for 4 simultaneous entries, each single entry would have to be 12 dB below the noise. Therefore, the long term minimum allowable carrier-to-interference (C/I) ratio should be about 25 dB. With nominal receive levels of about -115 dBw, the long term maximum permissible interfering signal levels would be about -140 dBw.*

*Interference levels to an earth station are statistical in nature and for short periods of time they may increase above their long term value. Again, to set the short term maximum permissible power, one must decide the degree of degradation he is willing to tolerate and for what percentage of time. If the C/I is reduced to 15 dB, the S/N begins to degrade, but usually not enough to be visible in the picture. If one decides this is acceptable for about an hour a year, the maximum permissible power level not to be exceeded 0.01% of the time would be about -130 dBw.*

*Many factors ultimately influence the final selection of an earth station site, the structural requirements being the most basic. Obviously, we must choose a site which has visibility of the satellite with which we wish to communicate. Protecting personnel from harmful radiation may play a part in the final selection. Finally, freedom from interference both to the earth station and to the terrestrial microwave system for transmit earth stations is an invisible but very important consideration.*

# CONTROL OF INTERFERENCE IN SATELLITE COMMUNICATION SYSTEMS

Dan Yost
Compucon, Inc.

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

# CONTROL OF INTERFERENCE IN SATELLITE COMMUNICATION

Abstract In the site selection process for satellite earth stations, unacceptable frequency interference at the selected ground terminal site often requires either relocation of the satellite earth station or an acceptable method of controlling the frequency interference by the use of interference suppression techniques. This paper describes the frequency interference environments for placing satellite earth stations receiving and transmitting in the 4 and 6 GHz frequency bands within the U.S.; the techniques for earth station site selection using Interference Intensity Map Overlays; available methods of interference suppression using passive shielding techniques such as antenna shrouding, fencing, pit shielding, etc.; available methods of interference suppression using active electronic interference cancellation; and the RFI field measurement as an analysis tool for evaluating potential frequency interference and the effectiveness of passive shielding techniques.

The control of frequency interference for the placement of satellite earth station terminals operating in the 4 and 6 GHz common-carrier frequency bands is a key for the rapid expansion of satellite communication within the U.S. The methods of eliminating potential interference conflicts and for identifying site locations of low frequency interference potential have improved with the use of smaller aperture earth station antennas. Most of the satellite earth station placement experience is being gathered in the small antenna markets where earth stations are proliferating at 30-40 per month.

Since the dedication of the first 10-meter satellite earth station antenna at UA-Columbia's Fort Pierce, Florida location for video reception, the pressure and justifications for smaller aperture earth station antennas have been increasing. Both the suppliers of satellite programming services and the prospective users as well as a large group of equipment suppliers have supported the FCC to take action without requiring a formal rulemaking procedure. In a declatory ruling issued in December, 1976, the FCC specifically allowed the use of earth station antenna sizes down to 4.5 meters in diameter after sifting the various arguments revolving around the previous 9-meter earth station antenna size guideline.

The impact of the FCC change in antenna size requirements has resulted in a rapid proliferation of small receive-only satellite earth station antennas, primarily for cable TV systems. The availability of satellite programming services is increasing as this network of large and small receive-only earth stations expands. Much of this proliferation is surprising considering that the receive-only earth stations must frequency coordinate with existing and proposed terrestrial microwave facilities. The existing networks of 4 GHz and 6 GHz terrestrial microwave routes are large, complex, and cover vast areas of the country.

In reviewing the engineering techniques for the analysis of prospective site locations for potential frequency interference, several areas of concern need to be addressed. This paper reviews the reasons for frequency coordination, the types of frequency interference mechanisms and the interference environment for small earth station antennas. In addition, the process of earth

station site selection is examined, the alternatives for controlling interference by passive and active interference suppression techniques considered and the role of on-site RFI field measurement analyzed. Finally, the FCC filing and licensing procedures are considered for planning and scheduling purposes.

### Reasons for Frequency Coordination

The satellite earth station receives transmissions from the domestic satellite in the frequency band 3700 MHz to 4200 MHz and transmits to the satellite in the frequency band 5929 MHz to 6425 MHz. The satellite using frequency reuse techniques has 24 satellite transponders centered at 20 MHz spacing with half of the transponders using horizontal polarization and half using vertical polarization. The RCA Satcom I and II have this configuration.

These same frequency bands are also allocated for common-carrier terrestrial microwave users such as AT&T, MCI, SPCC, etc. The terrestrial microwave networks at 4 GHz and 6 GHz have developed over the last 20 years into vast, complex route networks spanning the entire nation. In many areas of heavy population density, the design of new terrestrial microwave routes is difficult, if not impossible. Hence, the satellite earth station must consider the frequency interference from these potential sources of interference at 4 GHz for establishing receive-only capability, and at 6 GHz for potential interference into the terrestrial microwave receivers when transmitting.

The frequency interference analysis for a satellite earth station must consider proposed and planned microwave routes as well as existing microwaves. More than 20 percent of the microwave data bases are microwave routes which have been planned by the Bell system or other carriers and have not been built or filed with the FCC. Under Part 25.203 of the FCC Rules and Regulations the satellite earth station must frequency coordinate this application for 30 days with the surrounding common-carriers before filing an application with the FCC. Even for receive-only earth station applications, the common carriers must be concerned with the potential blockage of planned routes and system expansion on existing routes. There is no potential frequency interference between two satellite earth stations. Hence, there is no coordination between them.

The primary reason for frequency coordination of an earth station site is that the potential for frequency interference with terrestrial microwave routes is very real and can disrupt or seriously degrade a received signal. The interference can occur via interference mechanisms which require investigation and analysis, before coordinating a specific location. If interference is encountered in the analysis, there are techniques for artificially shielding the earth station to achieve satisfactory performance.

### Types of Frequency Interference Mechanisms

The satellite earth station designed for video reception must contend with the potential for frequency interference from 4 GHz microwave transmitters which may be located at considerable distances from the earth station. The design criteria based upon lab studies requires the interfering microwave signal to be at least 25 dB below the signal level received from the satellite. For a typical 10 meter earth station installation, the nominal received signal level from the satellite is −113 dBw which will vary with changes in satellite transponder and site location. In order to maintain acceptable margins above the interference thresholds, all interference signals should be below −138 dBw at 20 percent (in this case). For a small aperture antenna, this interference criteria for the same site location may be set at −145 dBw at 20 percent.

The first type of frequency interference mechanism of concern for the placement of the satellite earth station involves the great circle interference path. The direct path between the earth station site and the source of frequency

interference may be line-of-sight and encounter only free-space attenuation losses. If terrain, building or other ground clutter blockage exists preventing a line-of-sight radio path, then additional diffraction propagation losses will be encountered reducing the level of the interfering signal. Propagation via the tropospheric scatter may result in a potential frequency interference path and the associated tropospheric scatter losses. Figure 1A shows the possible interference paths which may occur over the great circle path. This type of frequency interference mechanism can utilize artificial site shielding techniques for reducing the interference levels.

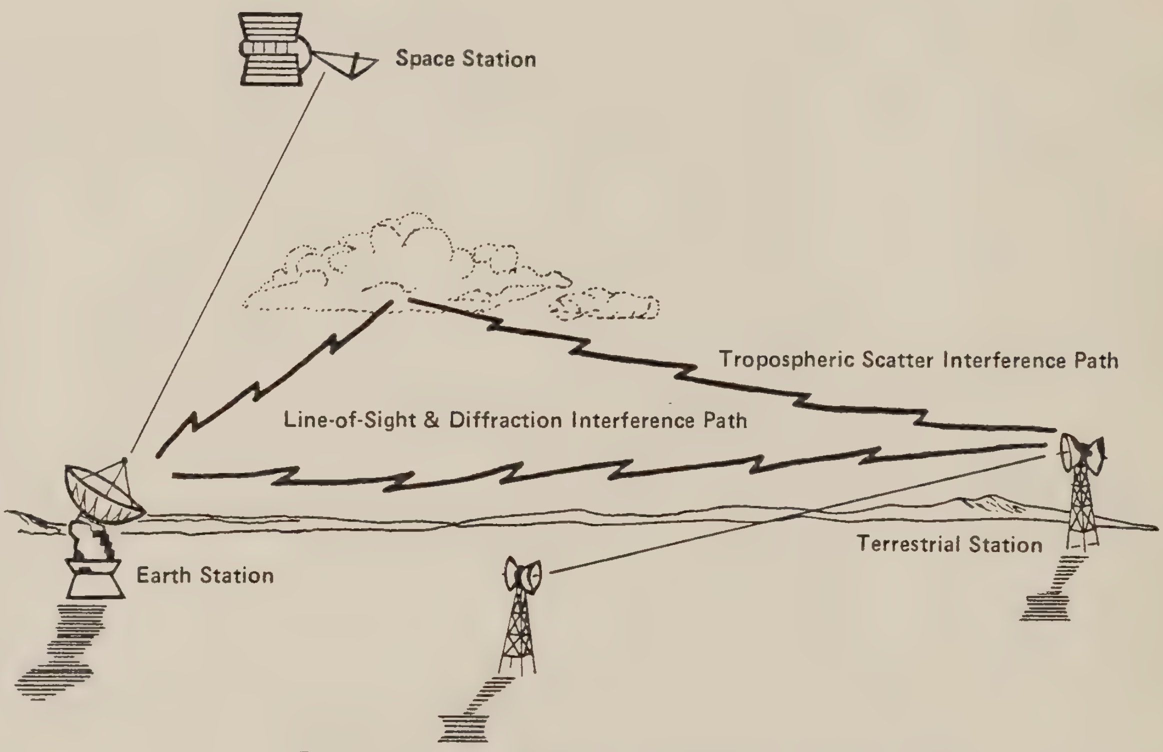



Figure 1A. Great Circle Interference with Shared Frequency Operation of Satellite and Terrestrial Microwave Systems.

The use of artificial site shielding or local ground clutter such as building structures and trees is common practice and can be an effective means of clearing a prospective site location which encounters problems. Passive interference reduction techniques would include using earth embankments, artificial pits, wire mesh fencing and dense trees as diffraction screens to reduce an interfering signal level. An alternate but more expensive approach would rely on active interference cancellers to receive the interfering signal, change its phase by 180° and mix it with the signal received at the earth station resulting in a cancellation of the interfering signal. Additional shielding can be obtained by adding shrouding to the earth station antenna to improve the antenna discrimination pattern, especially the front to back ratio. The smaller earth station antenna can be easier to shield due to its physical size and the dimensions required for shielding construction.

The second type of frequency interference mechanism, Figure 1B, involves the intersection of the satellite earth station beam and the terrestrial microwave beam. Within the common volume of this beam intersection, rain or other precipitation can cause scattering of the interfering signal from the 4 GHz microwave transmitter back into the earth station receiver. At 6 GHz, the reverse scatter impact can occur. Since the height of this common volume intersection can be at several kilometers, the use of local site shielding is ineffective. If a chosen site location encounters an interfering beam intersection, the only alternatives are to restrict the useable satellite orbital arc or relocate the earth station. Obviously, in clear sky conditions, this type of interference would not present a problem.

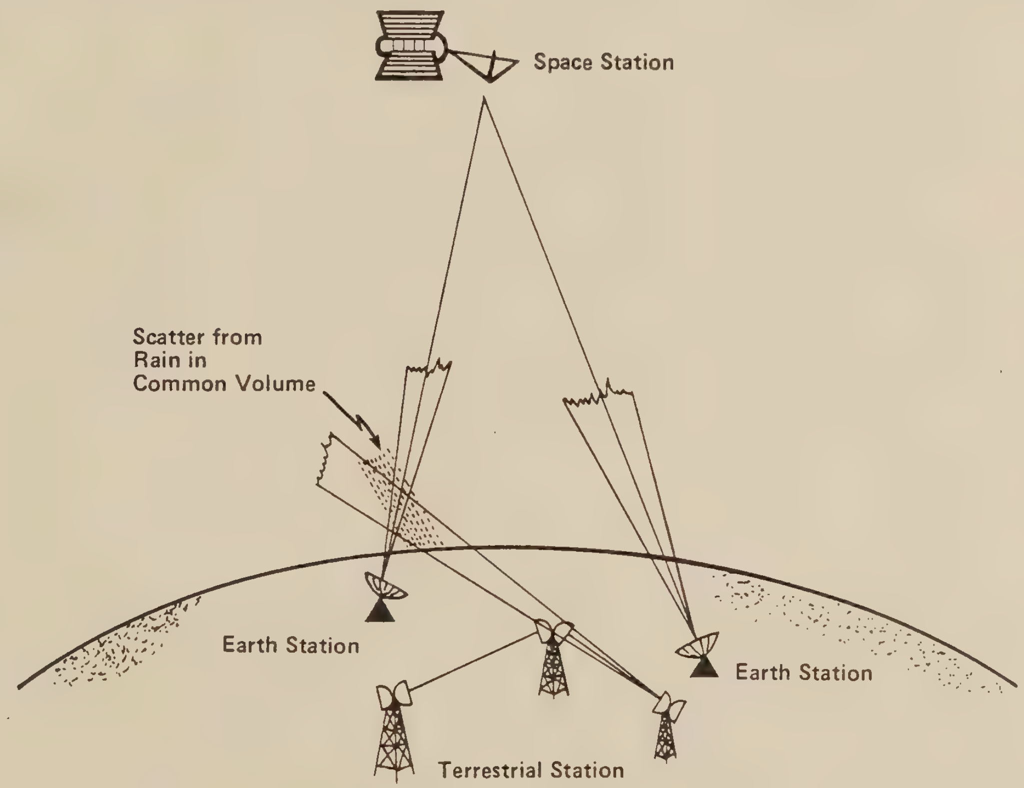



Figure 1B. Precipitation Scatter Interference with Shared Frequency Operation of Satellite and Terrestrial Microwave Systems.

## Evaluation of Small Earth Station Antenna Impact on the Frequency Interference Environment

A comparison of the small earth station antenna with the 10 meter and 9 meter antenna is important in understanding the current proliferation of small earth station antennas. The small antenna has a lower main beam gain which requires potentially interfering signals to be below a lower interference level than a 10 meter. Hence, the small antenna is more susceptible and sensitive to frequency interference and may not coordinate at locations which will clear for a 10 meter antenna. A wider main beam makes the small antenna more susceptible to adjacent satellite interference and will cause the earth station to have more beam intersections. A small antenna's gain pattern performance may be as good or better than a ten meter due to the FCC requirement to meet or exceed the 32-25 log $\theta$ curve. Shrouding on the small antenna further improves the antenna pattern performance for the side and back of the antenna.

Despite all of the above considerations, small antennas are proliferating. Why? The small antenna has a lower profile which can make a one story building look like an effective RF diffraction screen. Hence, the ease of shielding a small antenna with local building structures and artificial shielding can more than compensate for the loss in gain and the lower interference criteria. The small antenna does require careful design so that the carrier-to-noise margins above FM threshold are adequate over a number of satellite transponders and satellite orbital positions.

## Satellite Earth Station Site Selection Process

The characteristics of a good earth station site include adequate local site shielding, visibility to the satellite orbital arc and no interfering signals from terrestrial microwave transmitters. The earth station requires access and adequate power. But, given these characteristics, how does the site selection process work if the primary site location can not be cleared of frequency interference? Figure 2 shows an outline of a site selection procedure which systematically evaluates prospective earth station sites for receive and transmit capability.

If a primary site location encounters severe frequency interference problems which cannot be resolved by interference cancelling techniques, the search for an alternate site location does require some guidance. The identification of alternate earth station site locations needs some data concerning the potential for frequency interference as a function of location. Selection of feasible earth station site locations for interference analysis involves a coordination between (1) terrain topography, (2) anticipated land availability and (3) the potential interference impact of the proposed earth station on the surrounding microwave environment. Knowledge of the microwave environment is required to identify areas of least potential interference. Land availability surveys can indicate potential site locations with suitable zoning and environmental clearances with these areas.

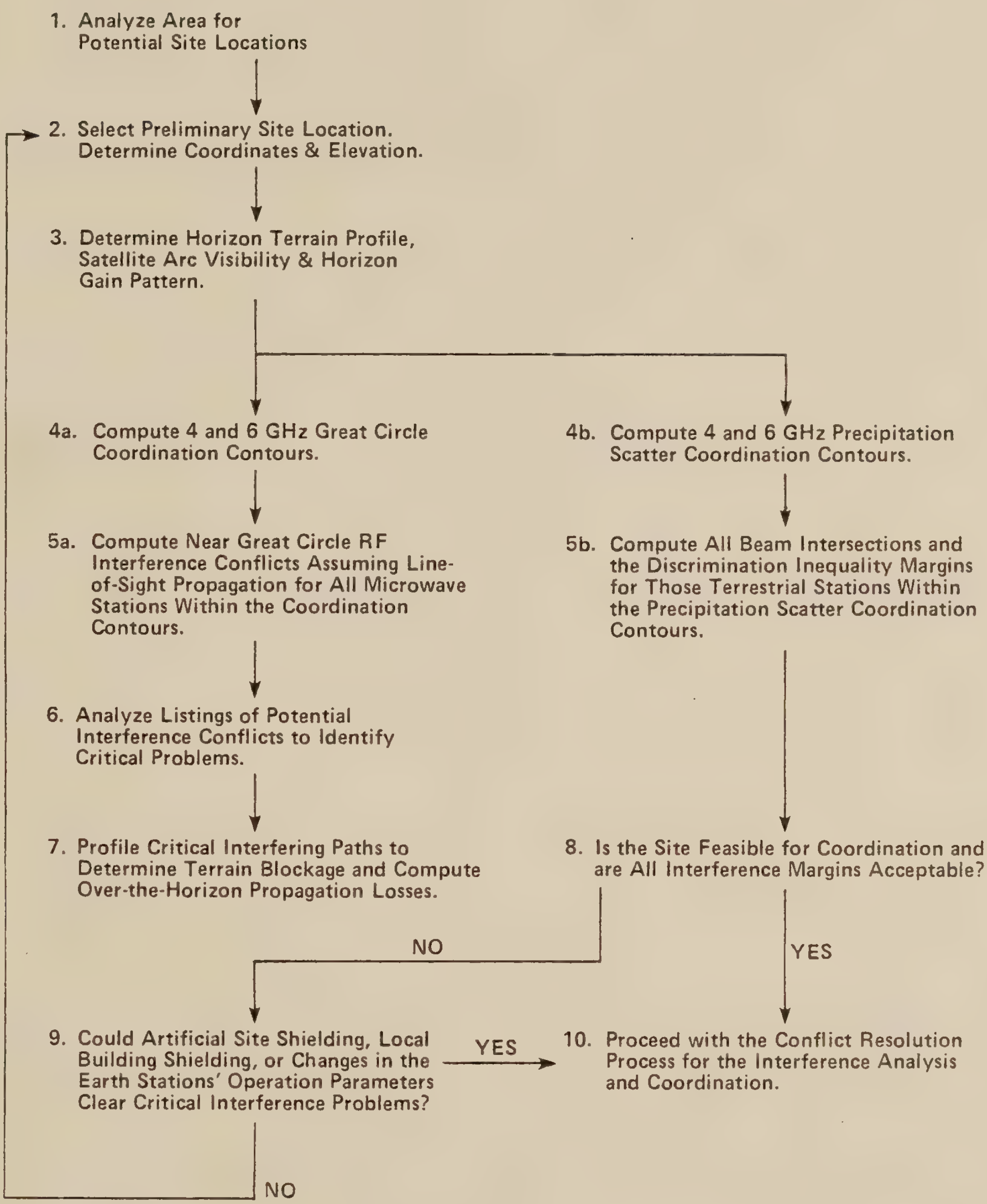



Figure 2. Satellite Earth Station Site Selection Process

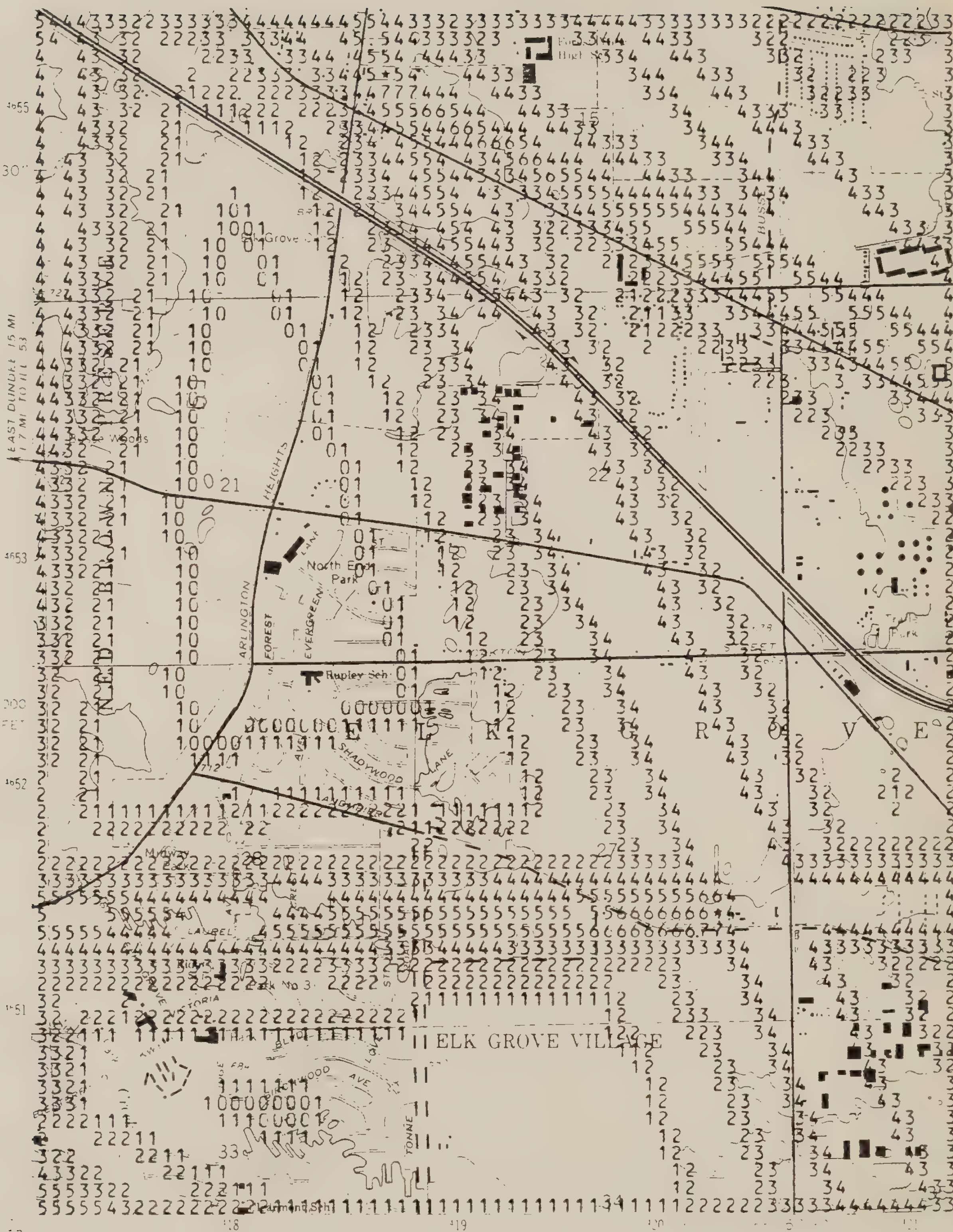



Figure 3. Interference Intensity Map Overlay

A computer technique using interference intensity map overlays is the most effective means of conducting site selection search. Map overlays shown in Figure 3 graphically display the potential interference intensity of the microwave environment for locating an earth station with specific parameters at each prospective site location. A proposed site location which is in a low interference area at both 4 GHz and 6 GHz would have a good probability of clearing for transmit/receive capability.

### Available Methods of Interference Suppression

Since the placement of satellite earth stations is often dictated by land availability as well as frequency interference, the demands for controlling frequency interference problems with interference suppression techniques leads to a serious review of the available alternatives in passive and active suppression hardware. The limits in shielding effectiveness and relative cost of these alternatives are important considerations in selecting the most efficient technique for reducing interfering signal levels. All of these interference suppression techniques are used primarily for eliminating sources of frequency interference over the great circle interference path. None of these techniques is particularly effective in interference suppression when the potential interference involves a precipitation scatter beam intersection occurring at several kilometers above ground level.

Passive interference suppression techniques involve the use of terrain, earth embankments, trees, buildings, and wire mesh fencing as artificial site shielding. The effectiveness of building structures and wire mesh fencing can be readily evaluated based upon the type of material, and the geometry of the shielding arrangement.[1] The use of "Builders Hardware Cloth" with 1/4" wire spacings has proved effective for reducing interference at 4 and 6 GHz which is less than 17 dB out of interference limits. Reflections off of surrounding structures can defeat the intent of the artificial site shielding if not eliminated. In some instances, RF absorption material may be required with fence shielding to prevent reflections of interfering signals off of the RF screen. The surface of the edge of the fence screen can have an impact on the shielding effectiveness in critical cases.[2]

The effectiveness of trees in reducing the level of interfering signals at an earth station has been well documented with numerous on-site RFI measurements. The shielding effect of dense tree growth appears to be a range of between 20 and 40 dB interference suppression. The obvious concerns with this type of site shielding involve the ability to evaluate different densities of trees and the effect of the loss of tree cover during the winter months. In addition, the permanence of trees is subject to some discussion even if the trees are on the applicant's property. A number of transmit/receive and numerous receive-only earth stations have been frequency coordinated and cleared of interference based solely on use of trees as artificial site shielding.

Pit shielding as an interference reduction technique can be very effective and very expensive. This type of site shielding provides a minimum of 25 dB of attenuation of interfering signals[3] and provides shielding in all directions. If low elevation angles are necessary to have visibility to all of the satellite orbital arc, the size of the pit can be rather large. The expense associated with this pit shielding varies widely but with requirements for earth moving and drainage the expense can approach $20,000 for a moderate size pit.

A final consideration of passive interference suppression technique focuses on the use of shrouding on the earth station antenna to reduce the sidelobes and backlobes of the antenna resulting in increased discrimination of the earth station antenna in the direction of most sources of terrestrial interference. The availability of shrouded antennas is very limited for sizes greater

than 4.5 meters diameter at present. An alternative to the antenna shrouding is the use of a conical horn antenna which can mean an addition of 30 dB of discrimination toward interference sources in the back and side of the antenna. Again, the limitations in size are a problem if performance standards cannot be met with a 14 foot conical horn.

Finally, an active interference suppression device can be obtained which will mix the interfering signal with the received signal and eliminate the source of interference. This technique is primarily applicable to satellite earth stations encountering interference at 4 GHz from a single interfering transmitter. The concept involves the use of a separate microwave antenna directed towards the source of interference which picks up the interfering signal and changes the phase 180° and mixes those interfering signals with the signal plus interference received at the earth station. Each source of interference at a different azimuth requires a separate antenna system and mixers. At present, this technique is expensive and not applicable to the typical interference situations encountered. For very specific interference conflicts which are out of limits, this active interference suppression might be a reasonable alternative to relocation of an earth station site.

### RFI Field Measurements

The on-site RFI field measurement of a prospective earth station site generally occurs if the frequency interference analysis indicates that the site has marginal clearance or the effectiveness of the local site shielding cannot be determined. The RFI measurement does encounter some difficulties since the interfering signals will vary with the time of day and the day of the year. Changes in local site shielding such as trees losing leaves may dramatically change the received signal level. In addition, the evaluation of planned or proposed routes is not practical since there are no on-the-air transmitters.

The field measurement is directed towards measuring interfering signals which occur via the great circle interference path. If a site location has encountered a serious beam intersection with a terrestrial microwave route, the RFI measurement cannot evaluate the interference impact. The on-site measurement does provide a means for detecting possible reflections of interference signals which could present a problem. In city locations, this reflection problem is of increasing concern and can only be analyzed on-site without extensive and time consuming calculations.

### FCC Filing and Licensing Procedures

The sequence of events and time period required for frequency coordination, FCC filing, Public Notice and Licensing is variable but may conform to the following schedule:

**Time and Event Schedule for Obtaining FCC License**

| | |
|---|---|
| 1. Frequency Interference Analysis | 5 - 10 days |
| 2. Part 25 Frequency Coordination | 30 days plus mail time |
| 3. FCC Application Preparation & Filing | 10 days |
| 4. FCC Public Notice | 30 days |
| 5. FCC Review and Grant of License | 8 - 60 days |

The earth station application does not require a specific FCC form and the contents of the application are specified in FCC Public Notices of August 8, 1975, and May 14, 1975. Applications for small receive-only earth station antennas also require an additional technical showing presenting the carrier-to-noise, carrier-to-interference and signal-to-noise calculations for the primary and backup satellites for all desired satellite transponders.

The proliferation of 10 meter and small aperture earth station antennas will contonue to occur as the applications of satellite technology expand. The success of the earth station placement effort is a contributing factor to the licensing of satellite earth stations within the vicinity of major population areas. The engineering techniques available allow a systematic approach for earth station site selection and frequency coordination.

References

1. J. Ruze, F.I. Sheftman, and D.A. Cahlander, "Radar Ground-Clutter Shields", Proceedings of the IEEE, Vol. 54, No. 9, Sept., 1966.
2. Elliott R. Nagelberg, "Limitations of Fence and Pit Shielding for Satellite Earth Stations", International Conference on Communications, IEEE, June, 1970.
3. Edward F. Lucia, Jr., "Artificial Site Shielding for Communication Satellite Earth Stations", IEEE Transactions on Aerospace and Electronics Systems, Vol. AES-6, No. 5, Sept., 1970.
4. George H. Hagn, Michael G. Keener, and Harry A. Turner, "Pit Shielding for Communication Satellite Ground-Terminal Antennas", IEEE Transactions on Electromagnetic Compatibility, June, 1965.

# FREQUENCY COORDINATION AND PLACEMENT CONSIDERATIONS FOR 10 METER AND SMALL APERATURE EARTH STATIONS


Dan Yost

Manager of Satellite Services

COMPUCON, INC.

Dallas, Texas


EARTH STATION TECHNOLOGY CONFERENCE

June 13 - 15, 1977

# FREQUENCY COORDINATION AND PLACEMENT CONSIDERATIONS FOR 10 METER AND SMALL APERATURE EARTH STATIONS

## INTRODUCTION

Since the dedication of the first 10 meter satellite earth station antenna at UA Columbias's Fort Pierce, Florida location for video reception, the pressure and justifications for smaller aperature earth station antennas have been increasing. Both the suppliers of satellite programming services and the prospective users as well as a large group of equipment suppliers have supported the FCC to take action without requiring a formal rule making procedure. In a declaratory ruling issued in December, 1976 the FCC specifically allowed the use of earth station antenna sizes down to 4.5 meters diameter after sifting the various arguments revolving around the previous 9 meter earth station antenna size guideline.

The impact of the FCC change in antenna size requirements has resulted in a rapid proliferation of small receive-only satellite earth station antennas, primarily for cable TV systems. The availability of satellite programming services is increasing as this network of large and small receive-only earth stations expands. Much of this proliferation is surprising when considering that the receive-only earth stations must frequency coordinate with existing and proposed terrestrial microwave facilities. The existing networks of 4 and 6 GHz terrestrial microwave routes are large, complex and cover vast areas of the country.

The key for the rapid expansion of satellite receive-only earth stations has been in the engineering technique for the analysis of prospective site locations for potential frequency interference. The following paper reviews the reasons for frequency coordination, the types of frequency interference mechanisms and the interference environment for small earth station antennas. In addition, the process of the earth station site selection is examined and the role of on-site RFI field measurement reviewed. Finally, the FCC filing and licensing procedures are considered for planning and scheduling purposes.

## REASONS FOR FREQUENCY COORDINATION

The satellite earth station receives transmissions from the domestic satellite in the frequency band 3700 MHz to 4200 MHz and transmits to the satellite in the frequency band 5925 MHz to 6425 MHz. The satellite using frequency reuse techniques has 24 satellite transponders centered at 20 MHz spacing with half of the transponders using horizontal polarization and half using vertical polarization. The RCA Satcom I and II have this configuration.

These same frequency bands are also allocated for common-carrier terrestrial microwave users such as AT&T, MCI,SPCC, etc. The terrestrial microwave networks at 4 and 6 GHz have developed over the last 20 years into vast, complex route networks spanding the entire nation. In many areas of heavy population density, the design of new terrestrial microwave routes is very difficult if not impossible. Hence, the satellite earth station must consider the frequency interference from these potential sources of interference at 4 GHz for establishing receive-only capability and at 6 GHz for potential interference into the terrestrial microwave receivers when transmitting. Figures 1 and 2 illustrate the microwave route density for any existing routes in the 4 and 6 GHz common carrier microwave bands.

The frequency interference analysis for a satellite earth station must consider proposed and planned microwave routes as well as those existing. More than 20% of the microwave data bases are microwave routes which have been planned by the Bell system or other carriers and have not been built or filed with the FCC. Under Part 25.203 of the FCC Rules and Regulations the satellite earth station must frequency coordinate this application for 30 days with the surrounding common-carriers before filing an application with the FCC. Even for receive-only earth station applications, the common-carriers must be concerned with the potential blockage of planned routes and system expansion on existing routes. There is no potential frequency interference between two satellite earth stations and hence, no coordination between them.

The primary reason for frequency coordination of an earth station site is that the potential for frequency interference with terrestrial microwave routes is very real and can disrupt or seriously



Figure 1 - 4 GHz Terrestrial Microwave Routes





Figure 2 - 6 GHz Terrestrial Microwave Routes

degrade a received signal. The interference can occur through a couple of interference mechanisms which require investigation and analysis before coordinating a specific site location. If interference is encountered in the analysis, there are techniques for artificially shielding the earth station to achieve satisfactory performance.

## TYPES OF FREQUENCY INTERFERENCE MECHANISMS

The satellite earth station designed for video reception must contend with the potential for frequency interference from 4 GHz microwave transmitters which may be located at considerable distances from the earth station. The design criteria based upon lab studies requires the interfering microwave signal to be at least 25 dB below the signal level received from the satellite. For a typical 10 meter earth station installation, the nominal received signal level from the satellite is -113 dBw which will vary with changes in satellite transponder and site location. In order to maintain acceptable margins above the interference thresholds, all interference signals should be below -138 dBw @20% in this case. For a small aperature antenna, this interference criteria for the same site location may be set at -145 dBw @20%.

The first type of frequency interference mechanism of concern for the placement of the satellite earth station involves the great circle interference path. The direct path between the earth station site and the source of frequency interference may be line-of-sight and encounter only free-space attenuation losses. If terrain, building or other ground clutter blockage exists preventing a line-of-sight radio path, then additional diffraction propagation losses will be encountered reducing the level of the interfering signal. Propagation via the tropospheric scatter may result in a potential frequency interference path and the associated tropospheric scatter losses. Figure 3 shows the possible interference paths which may occur over the great circle path. This type of frequency interference mechanism can utilize artificial site shielding techniques for reducing interference levels.

The use of artificial site shielding or local ground clutter such as building structures and trees is common practice and can be an effective means of clearing a prospective site location which encounters problems. Passive interference reduction techniques would include using earth embankments, artificial pits, wire

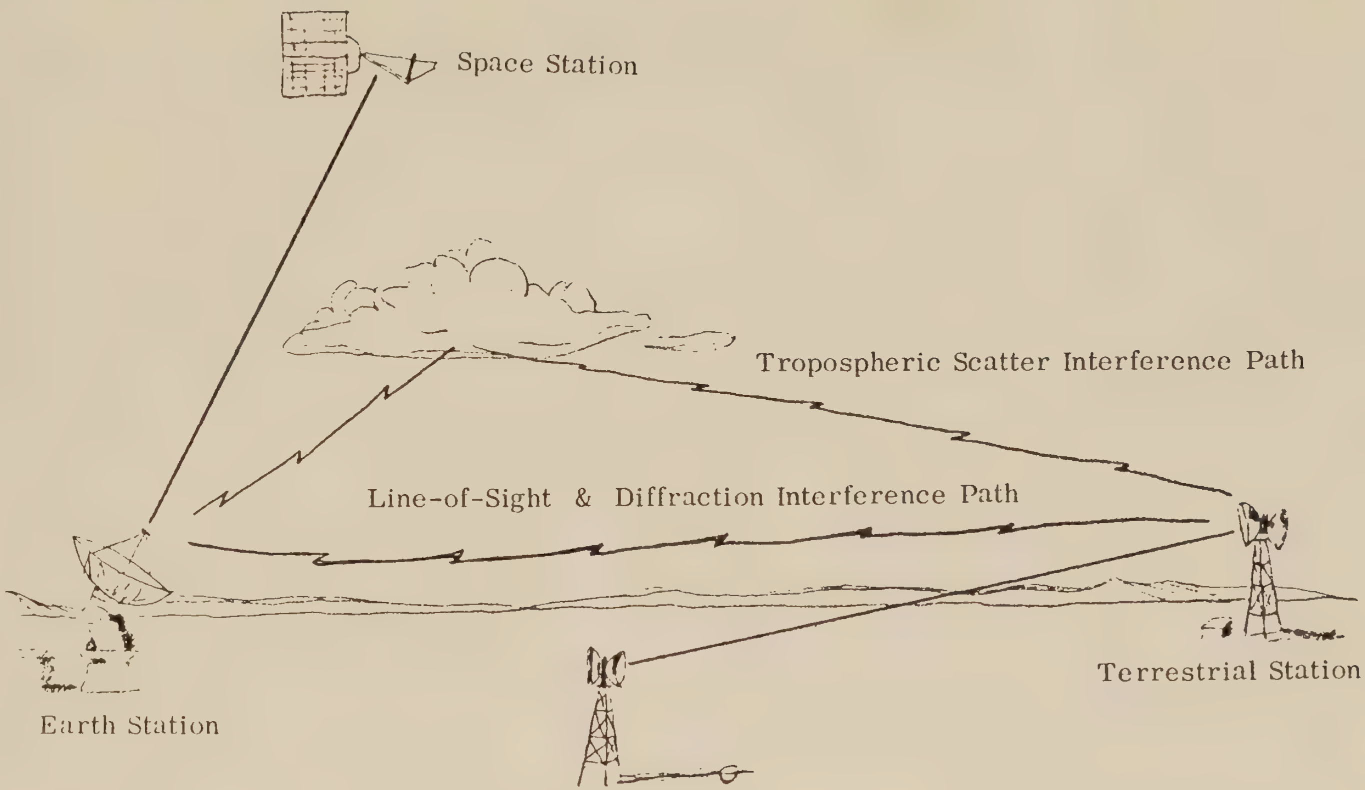



Figure 3A Great Circle Interference with shared frequency operation of satellite and terrestrial microwave systems.

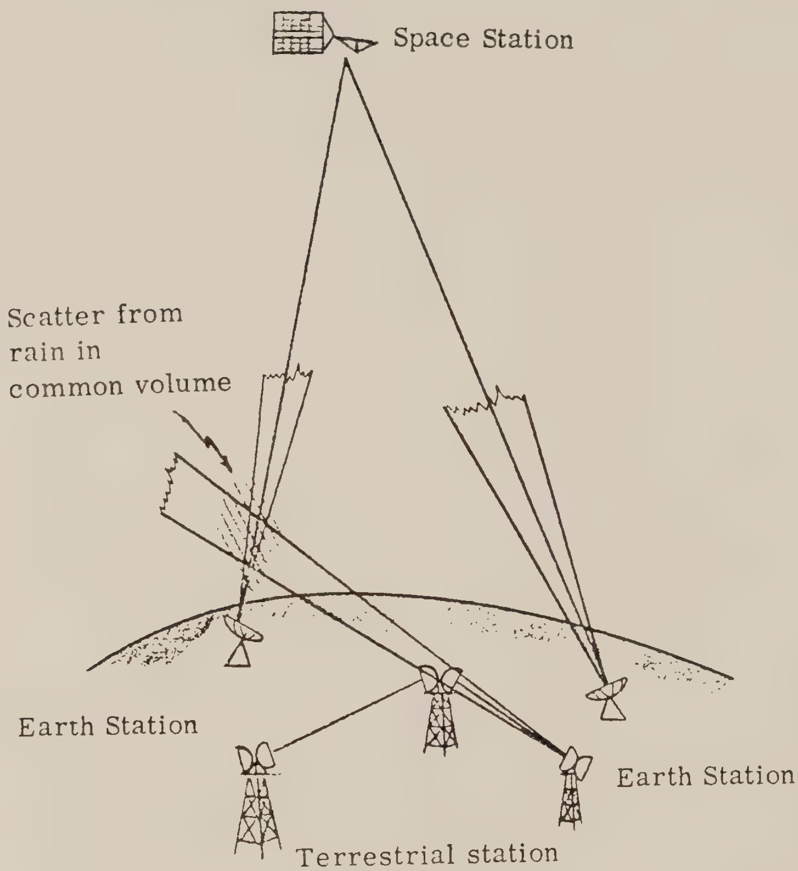



Figure 3B Precipitation Scatter Interference with shared frequency operation of satellite and terrestrial microwave systems.

mesh fencing and dense trees as diffraction screens to reduce an interfering signal level. An alternate but more expensive approach would rely on active interference cancellers to receive the interfering signal, change its phase by $180^{\circ}$ and mix it with the signal received at the earth station resulting in a cancellation of the interfering signal. Additional shielding can be obtained by adding shrouding to the earth station antenna to improve the antenna discrimination pattern, especially the front to back ratio. The smaller earth station antenna can be easier to shield due to its physical size and the dimensions required for shielding construction.

The second type of frequency interference mechanism involves the intersection of the satellite earth station beam and the terrestrial microwave beam. Within the common volume of this beam intersection, rain or other precipitation can cause scattering of the interfering signal from the 4 GHz microwave transmitter back into the earth station receiver. At 6 GHz, the reverse scatter impact can occur. Since the height of this common volume intersection can be at several kilometers, the use of local site shielding is ineffective. If a chosen site location encounters an interfering beam intersection, the only alternatives are to restrict the useable satellite orbital arc or relocate the earth station. Obviously, in clear sky conditions, this type of interference would not present a problem.

## EVALUATION OF SMALL EARTH STATION ANTENNA IMPACT ON THE FREQUENCY INTERFERENCE ENVIRONMENT

A comparison of the small earth station antenna with the 10 meter and 9 meter antenna is important in understanding the current proliferation of small earth station antennas. The small antenna has a lower main beam gain which requires potentially interfering signals to be below a lower interference level than a 10 meter. Hence, the small antenna is more susceptible and sensitive to frequency interference and may not coordinate at locations which will clear for a 10 meter antenna. A wider main beam makes the small antenna more susceptible to adjacent satellite interference and will cause the earth station to have more beam intersections. A small antennas' gain pattern performance may be as good or better than a ten meter due to the FCC requirement to meet or exceed the 32-25 log Θ curve. Shrouding on the small antenna further improves the antenna pattern performance for the side and back of the antenna.

Despite all of the above considerations, small antennas are proliferating. Why? The small antenna has a lower profile which can make a one story building look like an effective RF diffraction screen. Hence, the ease of shielding a small antenna with local building structures and artificial shielding can more than compensate for the loss in gain and the lower interference criteria. The small antenna does require careful design so that the carrier-to-noise margins above FM threshold are adequate over a number of satellite transponders and satellite orbital positions.

## SATELLITE EARTH STATION SITE SELECTION PROCESS

The characteristics of a good earth station site include adequate local site shielding, visibility to the satellite orbital arc and no interfering signals from terrestrial microwave transmitters. The earth station requires access and adequate power. But, given these characteristics, how does the site selection process work if the primary site location can not be cleared of frequency interference? Figure 4 shows an outline of a site selection procedure which systematically evaluates prospective earth station sites for receive and transmit capability.

If a primary site location encounters severe frequency interference problems which cannot be resolved by interference cancelling techniques, the search for an alternate site location does require some guidance. The identification of alternate earth station site locations needs some data concerning the potential for frequency interference as a function of location. Selection of feasible earth station site locations for interference analysis involves a coordination between (1) terrain topography, (2) anticipated land availability and (3) the potential interference impact of the proposed earth station on the surrounding microwave environment. Knowledge of the microwave environment is required to identify areas of least potential interference. Land availability surveys can indicate potential site locations with suitable zoning and environmental clearances with these areas.

A computer technique using interference intensity map overlays is the most effective means of conducting the site selection search. These map overlays, Figure 5, graphically display the potential interference intensity of the microwave environment for locating an earth station with specific parameters at each prospective site location. Separate map overlays are prepared for

Figure 4

## SATELLITE EARTH STATION

### Site Selection Process

1) Analyze Area for Potential Site Locations.

2) Select Preliminary Site Location. Determine Coordinates & Elevation.

3) Determine Horizon Terrain Profile, Satellite Arc Visibility & Horizon Gain Pattern.

4a) Compute 4 and 6 Ghz Great Circle Coordination Contours

4b) Compute 4 and 6 Ghz Precipitation Scatter Coordination Contours.

5a) Compute near Great Circle RF Interference conflicts assuming LOS Propagation for all Microwave stations within the coordination contours.

5b) Compute all Beam Intersections & the discrimination inequality margins for thos terrestrial stations within the coordination contours.

6) Analyze Listings of potential Interference Conflicts to identify Critical Problems.

7) Profile Critical interfering paths to determine Terrain Blockage and compute over-the-horizon Propagation losses.

8) Is the Site Feasible for Coordination and are all Interference margins acceptable?

9) Could Artificial site shielding, Local building shielding or changes in the Earth Station's Operation Parameters clear Critical Interference Problems?

10) Proceed with the Conflict resolution process for the Interference Analysis & Coordination.

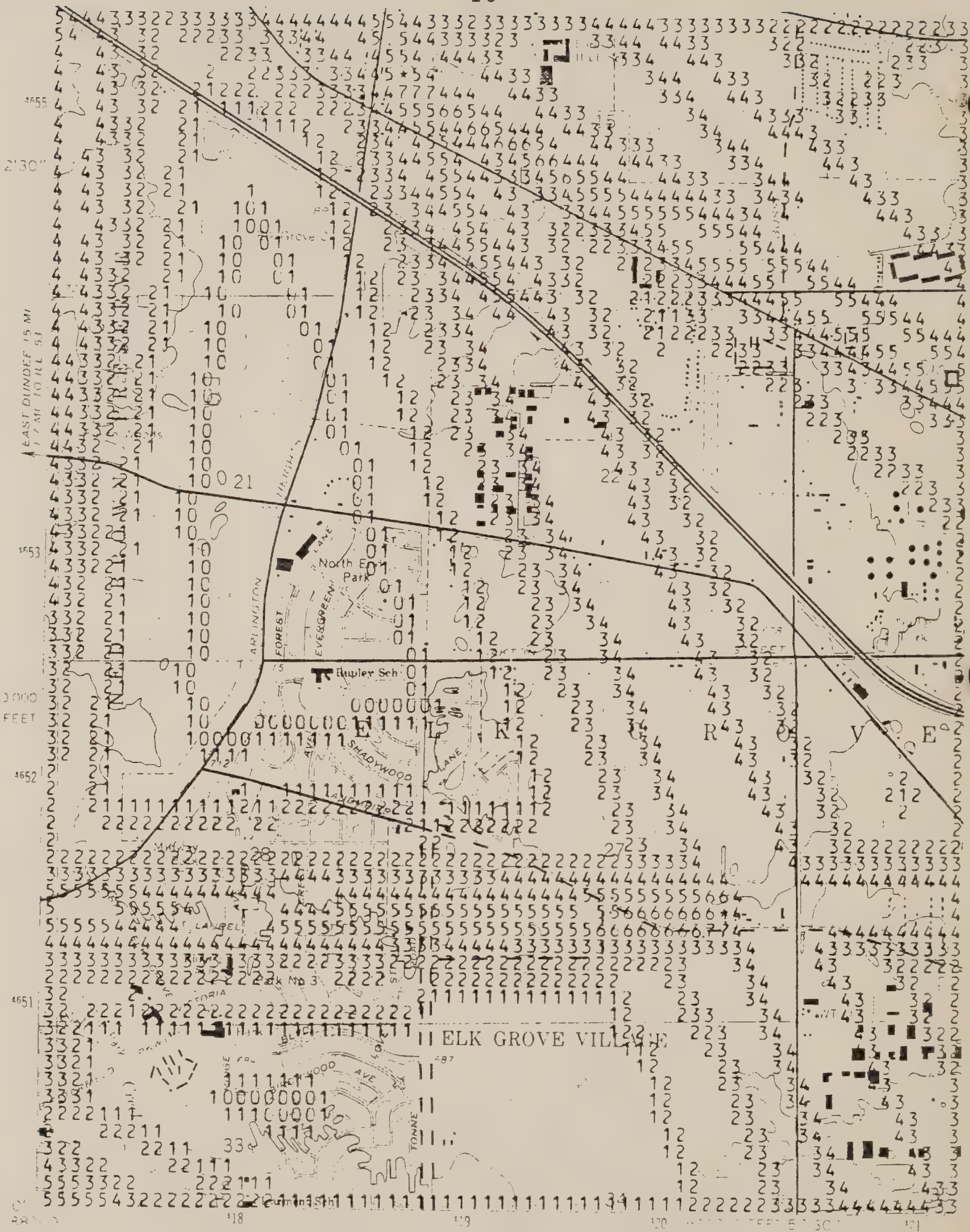



FIGURE 5 INTERFERENCE INTENSITY MAP OVERLAY
Composite Mapping of Regions of Interference Impact for the 4 GHz Microwave Routes within a Region.

receive and transmit capability at 4 and 6 GHz. A proposed site location which is in a low interference area at both 4 and 6 GHz would have a good probability of clearing for transmit/receive capability. The number coding shown in Figure 5 times 10 represents the maximum amount of additional dB of diffraction propagation loss at 20% of the time required to clear the interference criteria. Since the interference power levels are computed assuming line-of-sight transmissions, the examination of terrain is required when locating any earth station site.

Generally, areas of 3's or less are the prime areas to concentrate the search for prospective earth station sites. If an area has hilly or rolling terrain which might provide shielding, areas of 4's should also be considered. Since frequency interference is a vector quantity, it has both magnitude and direction. The map overlays show worst case magnitude of interference but does not indicate the direction of the interference. By observing the directions of increasing and decreasing numbers, a sense of direction can be deduced from the map overlay to help in the selection of an earth station site with adequate site shielding.

The difference between locating a 10 meter and small aperature earth station with map overlays is easily demonstrated. A map overlay prepared for a 10 meter earth station will change by slightly less than one number code on the map overlay. Hence, a proposed site located in an area of 3's on the 10 meter map overlay might be in an area of 4's for placing a small aperature earth station. Sites have been placed in areas of 5's and even 6's on occasions where substantial blockage was available to prevent frequency interference. Sites in areas of 6's - up are more likely to encounter common volume beam intersections with terrestrial microwave routes which are seriously interfering.

## RFI FIELD MEASUREMENTS

The on-site RFI field measurement of a prospective earth station site generally occurs if the frequency interference analysis indicates that the site has marginal clearance or the effectiveness of the local site shielding cannot be determined. The RFI measurement does encounter some difficulties since the interfering signals will vary with the time of day and the day of the year. Changes in local site shielding such as trees losing leaves may dramatically change the received signal level. In addition, the evaluation of

of planned or proposed routes is not practical since there are no on-the-air transmitters.

The field measurement is directed towards measuring interfering signals which occur via the great circle interference path. If a site location has encountered a serious beam intersection with a terrestrial microwave route, the RFI measurement cannot evaluate the interference impact. The on-site measurement does provide a means for detecting possible reflections of interference signals which could present a problem. In city locations, this reflection problem is of increasing concern and can only be analyzed on-site without extensive and time consuming calculations.

## FCC FILING AND LICENSING PROCEDURES

The sequence of events and time period required for frequency coordination, FCC filing, Public Notice and Licensing is variable but may conform to the following schedule:

Time and Event Schedule for Obtaining FCC License

| | | |
|---|---|---|
| 1) | Frequency Interference Analysis | 5-10 days |
| 2) | Part 25 Frequency Coordination | 30 days plus mail time |
| 3) | FCC Application Preparation & Filing | 10 days |
| 4) | FCC Public Notice | 30 days |
| 5) | FCC Review and grant of license | 8-60 days |

The earth station application does not require a specific FCC form and the contents of the application are specified in FCC Public Notices of August 8, 1975 and May 14, 1975. Applications for small receive-only earth station antennas also require an additional technical showing presenting the carrier-to-noise, carrier-to-interference and signal-to-noise calculations for the primary and back-up satellites for all desired satellite transponders. An example of this additional technical showing for small receive-only video earth stations is provided in Figure 6.

The proliferation of 10 meter and small aperature earth station antennas will continue to occur as the applications of satellite technology expand. The success of the earth station placement effort is a contributing factor to the licensing of satellite earth stations within the vicinity of major population areas. The engineering techniques available allow a systematic approach for earth station site selection and frequency coordination.

TECHNICAL ANALYSIS OF A SMALL RECEIVE-ONLY EARTH STATION
FOR A CABLE TELEVISION SYSTEM

CARROLL CABLE TV — CARROLL, IOWA
42D 5M 30S LATITUDE
94D 54M 0S LONGITUDE

SMALL EARTH STATION TECHNICAL CHARACTERISTICS

| | | | | |
|---|---|---|---|---|
| ANTENNA | MANUFACTURER | S-A | SATELLITE RANGE | 70-135DEG |
| | MODEL | 500KA | MINIMUM ELEVATION ANGLE = 26.8DEG | |
| | SIZE | 5.0 METERS | | |
| | GAIN | 44.5 DBI | ANTENNA TEMPERATURE = 20.0K | |
| LNA | MANUFACTURER | S-A | RECEIVER MANUFACTURER | S-A |
| | MODEL | | MODEL | SA4414 |
| | NOISE TEMP | 120.0K | FM THRESHOLD | 10.0DB |

T(SYSTEM) = T(ANT) + T(LNA)/GFEED + T(RCVR)/((GFEED)(GLNA)) =142.4 K
G/T = G(ANT) - 10LOG(T(SYSTEM)) = 22.9 DB/K

DOMESTIC SATELLITE CHARACTERISTICS - SATCOM SATELLITE 119.0W

| SATELLITE TRANSPONDER | EIRP(SAT) | G/TSAT | EIRP(ES) |
|---|---|---|---|
| 6 (3820.0 MHZ) | 35.5 DBW | -0.8 DB/K | 85.6 DBW |
| 8 (3860.0 MHZ) | 36.4 DBW | -0.8 DB/K | 85.6 DBW |
| 20 (4100.0 MHZ) | 36.4 DBW | -0.8 DB/K | 85.6 DBW |
| 22 (4140.0 MHZ) | 35.5 DBW | -0.8 DB/K | 85.6 DBW |
| 24 (4180.0 MHZ) | 36.4 DBW | -0.8 DB/K | 85.6 DBW |

PERFORMANCE EVALUATION BASED UPON SATELLITE TRANSPONDER

TECHNICAL ANALYSIS

I CARRIER-TO-NOISE CALCULATIONS

II CARRIER-TO-INTERFERENCE CALCULATIONS

III SIGNAL-TO-NOISE CALCULATIONS

NS

O AT THE RECEIVER OUTPUT

LOG(B/FVM) +10LOG(6) +EW)

EQUENCY
IGHTING IMPROVEMENT

4.4 DB

ATIO
OF AUDIO SUBCARRIER

**3)(FSC**2))) -K +EA

RY SUBCARRIER
TION
EQUENCY

EMENT

DB/K

C) COMMENTS ON PERFORMANCE EVALUATION OF TV R/O EARTH STATION

BASED UPON THE ABOVE PERFORMANCE CALCULATIONS, THE SIGNAL-TO-NOISE PERFORMANCE BY SATELLITE TRANSPONDER OF INTEREST IS SUMMARIZED IN THE FOLLOWING TABLE -

| SATELLITE TRANSPONDER | EIRP(SAT) | C/NTH CLR SKY | C/NTH WOR CASE | S(P-P) / N(RMS) | S/N (AUDIO) |
|---|---|---|---|---|---|
| 6 (3820.0 MHZ) | 35.6 DBW | 15.6 DB | 12.0 DB | 52.2 DB | 52.6 DB |
| 8 (3860.0 MHZ) | 35.7 DBW | 15.7 DB | 12.1 DB | 52.3 DB | 52.6 DB |
| 20 (4100.0 MHZ) | 35.7 DBW | 15.7 DB | 12.1 DB | 52.3 DB | 52.6 DB |
| 22 (4140.0 MHZ) | 35.6 DBW | 15.6 DB | 12.0 DB | 52.2 DB | 52.6 DB |
| 24 (4180.0 MHZ) | 35.7 DBW | 15.7 DB | 12.1 DB | 52.3 DB | 52.6 DB |

Figure 6 - Technical Analysis of a Small Receive - only Earth Station

# PROCESSING PROCEDURES FOR DOMESTIC EARTH STATION APPLICATIONS. DISCUSSION OF FCC PERMIT AND LICENSING REQUIREMENTS

Jay Ricks
of
Hogan & Hartson

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## OUTLINE OF EARTH STATION FCC AUTHORIZATION PROCEDURES

I. Must secure site, locate by geographic coordinates, and obtain right to construct (including building permit) and operate earth station.

II. Frequency coordination for earth station and terrestrial microwave.
   A. Must perform interference analysis by notifying every affected terrestrial station licensee, permittee, and prior filed applicant of the technical specifications of the proposed station.
   B. Allow at least thirty days for responses before filing application.

III. Pre-filing considerations.
   A. FCC's decisions in Docket No. 16495 are controlling.
      1. No formally adopted rules.
      2. No form for construction permit.
   B. FCC's informal policies concerning private and common carrier earth stations.
      1. Must be a common carrier facility to provide service to others for for profit. Imposes obligation to offer service to the public. Applicability of Section 214.
      2. May share service from private earth station on cost-sharing basis upon appropriate application to FCC.

IV. Application Process.
   A. Each applicant must complete and file FCC Form 430 (Licensee Qualification Report reflecting legal qualifications and ownership of applicant).
   B. Application for Construction Permit.
      1. Describe applicant and its technical and financial qualifications.
      2. Proposed usage and public interest considerations.
         a. Briefly describe the nature and proposed operation of the earth station and the services to be provided, including location of the station and points of communication. Applicants for private receive-only stations may specify a single channel of programming and request authority to receive all other programming which is available on the specified satellite and which they are authorized to receive by programming suppliers.
         b. Estimate construction schedule — this is used to determine duration of construction permit.
         c. Show how the public interest will be served — e.g., provide additional entertainment alternatives consistent with FCC's rules.
      3. Discussion of technical aspects.
         a. Brief description of proposed facility.
         b. Location, elevation, and distance to nearest aircraft landing area.
         c. Limits of receivable satellite range and method of adjustment.
         d. Frequency range — e.g., 3.7 to 4.2 GHz receive band and specified frequencies in the 6 GHz transmit band.
         e. Exhibit 2 detailing results of the coordination and interference analysis referred to in II above.
         f. Radiation study for transmit stations to protect against non-ionizing radiation.
         g. Supplemental technical showing for antennas having diameters of less than 9 meters.

Receive — performance objectives and detailed calculations by frequency coordinator to demonstrate at least a 1 dB margin above FM threshold of the receiver.

Transmit — impact on 4° inter-satellite spacing.

4. Environmental considerations.
   a. If antenna is an excess of 30 feet in diameter, application is a "major action".
   b. Describe site and surrounding area and its use.
   c. Discuss environmental and other considerations which led to site selection.
   d. Statement regarding zoning classification of the site.
   e. Statement as to whether proposed construction has been a source of controversy on environmental grounds.
   f. Discuss nature and extent of any unavoidable adverse environmental effects and efforts made to minimize those effects.
   g. Statement as to any effect on sites, building, structures eligible for listing in the National Register of Historic Places.
5. Certifications:
   a. The applicant waives any claim to the use of any particular frequency or of the ether as against the regulatory power of the United States because of the previous use of the same, whether by license or otherwise.
   b. I, ______________________, hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this application, that I am familiar with Part 25 of the Commission's Rules, that I have either prepared or reviewed the engineering information submitted in this application, and that it is complete and accurate to the best of my knowledge.
   c. The undersigned, individually, and on behalf of the applicant, hereby certifies that the statements made herein are true, complete, and correct to the best of his knowledge and belief, and are made in good faith.

      Dated this __________ day of ______________, 19___.

      Applicant ________________________________

      By ________________________________

      Title ________________________________
6. Other exhibits.
   a. Map showing location of proposed site.
   b. Profile sketch indicating heights of facility and elevation of site.
   c. Block diagram of transmit and receiving system.
   d. Technical characteristics (sample attached).
   e. Estimated cost of facility.
7. Miscellaneous.
   a. FAA notification is necessary only if station is to be located close to an airport runway.
   b. No filing fee necessary at present.

E. Processing of Application.
   1. Application will be placed on public notice. (Allow 7 to 15 days).
   2. Thirty-day period from date of public notice in which objections may be filed.
   3. Current processing time for unopposed applications which are consistent with the Rules is approximately 60 days from date filed. STA requests will not be routinely granted.

4. No on-site construction is permitted until a construction permit has been issued.

F. Application for license on FCC Form 403 must be granted prior to commencement of service.
   1. May be filed simultaneously with construction permit application if construction is to be completed within ninety days of issuance of the construction permit.
   2. If construction will not be completed within ninety days of construction permit grant, the license application is to be filed upon completion of construction. License application may be filed prior to completion of construction by specifying date construction will be complete.

G. If the applicant proposes to operate the facility as a common carrier, it is necessary to file:
   1. An application requesting authority pursuant to Section 214 of the Act to operate Channels of Communications through the earth station facility.
   2. A tariff specifying the terms and conditions upon which service will be offered to the public.

H. If the applicant proposes to change or supplement the authorized facility or services, such as changing the points of communication or providing service to others, then prior approval of the FCC must be obtained by filing an application for modification of license on FCC Form 403.

## Technical Exhibit for Video Receive-Only Earth Stations

| | |
|---|---|
| Name of Station: | ______________________ |
| Type of System: | Receive Only Satellite Earth Station |
| Geographical Coordinates: | Lat. ______________________ |
| | Long. ______________________ |
| Ground Elevation | AMSL |

| | |
|---|---|
| *Operating Frequency Range* | *3.7 to 4.2 GHz* |
| *Antenna Size* | *Diameter 33 ft.* |
| *Antenna Gain (4.0 GHz)* | *dB min.* |
| *G/T (4.0 GHz) 20° elevation* | *dB* |
| *Antenna Noise Temperature vs. Elevation* | |
| *5° Elevation - 55°K* | *30° Elevation - °K* |
| *10° Elevation - 38°K* | *40° Elevation - °K* |
| *15° Elevation - 28°K* | *60° Elevation - °K* |
| | *90° Elevation - °K* |
| *Polarization Capability* | |
| *Azimuth Positioning Two overlapping sectors of 52° each)* | |
| *Height of Antenna Center Line Above Base* | |
| *Feed Type* | |
| *Maximum Height of Antenna Above Base* | *at 0° Elevation* |
| *3 dB Beam Width* | *at 3950 MHz* |
| *15 dB Beam Width* | *at 3950 MHz* |
| *Operating Temperatures* | |
| *Outside Equipment* | *C* |
| *Electronic (Inside Equipment)* | *C* |
| *Longitude of Satellite* | *°* |
| *Maximum Permissible RF Interference* | |
| *Elevation Angle of Receiver* | |
| *Azimuth of Receiver from True North* | |
| *Emission Designator* | |

Sample
Exhibit Form

ADDITIONAL INFORMATION for TRANSMIT/RECEIVE APPLICATIONS

APPLICANT'S NAME:

SITE LOCATION: (City, County, State)

SERVICE:

A) Domestic Fixed Satellite
B) Fixed Earth Station
C) Private
D) Transmit/Receive

LATITUDE:

LONGITUDE:

OPERATING BANDS:

POINTS OF COMMUNICATION: (Satellites)

SITE ELEVATION: (meters and feet AMSL)

RANGE OF SATELLITE ARC:

ELEVATION ANGLE RANGE:

EARTH STATION AZMIUTH RANGE:

MAXIMUM E.I.R.P. TOWARD THE HORIZON:

TRANSMITTER EQUIPMENT

A) Number of transmitters
B) Manufacturer/Model number
C) Power output (watts or kilowatts)
D) Tolerance

ANTENNA FACILITIES:

A) Communications
B) Size in meters
C) Type of Feed
D) Manufacturer/model number
E) Gain(s) @ measured frequency
F) Maximum Height (meters and feet agl and amsl)
G) 3 db beamwidth(s)

REMOTE CONTROL: Yes or No (If yess indicate location of control)

RECEIVING SYSTEM NOISE TEMPERATURE: °K at elevation angle and frequency

FREQUENCIES:

| Transmit/Receive | Frequency range | Pol. | Emission | E.I.R.P. | Density/4KHz |
|---|---|---|---|---|---|

PUBLIC NOTICE

Federal Communications Commission ▪ 1919 M Street, N.W. ▪ Washington, D.C. 20554

August 8, 1975 - C
36476
FCC 75-932

PROCESSING PROCEDURES FOR DOMESTIC SATELLITE
EARTH STATION APPLICATIONS

1. In addition to the requirements specified in the First Report and Order in Docket No. 16495 1/, the Commission issued a Public Notice on November 9, 1972 (FCC 72-992) pursuant to the Second Report and Order in that docket establishing certain general procedures for processing domestic satellite applications. That Public Notice provides in part that:

> Should any question of general applicability arise in the course of processing, which appears to warrant clarification for the benefit of pending and/or future applicants, the Commission may issue a further public notice concerning processing procedures or take such other appropriate measures as in its judgment would best serve the public interest.

In order to assist potential domestic satellite earth station applicants and provide for a more orderly and efficient application processing procedure, the following guidelines are being issued at this time. It should be noted that, in addition to the following requirements applicable to all applications, further information or showings may be required with respect to any application. 2/

---

1/ 22 FCC 2d 86 (1970). This First Report and Order, together with the Commission's Memorandum Opinion and Order, 34 FCC 2d 1 and 9, (1972), Second Report and Order, 35 FCC 2d 844 (1972), and Memorandum Opinion and Order on reconsideration, 38 FCC 2d 665 (1972), set forth the basic domestic satellite policies adopted in Docket No. 16495.

2/ Additional Public Notices were also issued on February 26, 1974 (Mimeo 18850) concerning Section 319(d) waiver requests (Attachment 1) and on May 14, 1975 (Mimeo 50233) concerning limited frequency coordination and antenna steering capabilities (Attachment 2) which are still applicable.

## Earth Station Construction Permit Applications

2. No specific FCC form is available for earth station construction permit applications, except in the case of developmental earth stations. 3/ The format of construction permit applications should therefore be generally in conformance with the specifications set forth in §1.49 of the Rules and Regulations, and the caption should identify the applicant and the city and state at which the proposed station is to be constructed. Receive-only, transportable, and developmental earth stations should be identified as such in the caption. An original and nine copies of the application should be filed with the Commission.

3. The overall earth station proposal should be contained in the captioned portion of the application, with supporting details and showings in attached exhibits. This main portion of the application should include at least the following items:

(a) a brief, overall description of the nature and operation of the proposed earth station facilities and the communications services to be provided;

(b) the legal, financial, technical, and other qualifications of the applicant;

(c) a showing of why the public interest would be served by a grant of the application;

(d) a statement as to whether the proposed construction is a "major" or "minor" action within the meaning of §1.1305 of the Rules and Regulations on environmental considerations;

(e) the name and address of the person to whom correspondence relating to the application should be addressed and, if appropriate, counsel; and

(f) the waiver required by Section 304 of the Communications Act of 1934. 4/

---

3/ The requirement specified in §25.309(d) that FCC Form 401 be used for developmental earth station applications will be waived on request if the application is otherwise in conformance with these guidelines.

4/ Section 304: "No station license shall be granted by the Commission until the applicant therefore shall have signed a waiver of any claim to the use of any particular frequency or of the ether as against the reglatory power of the United States because of the previous use of the same, whether by license or otherwise."

4. It is suggested that applicants utilize FCC Form 430 to establish basic legal qualifications by attaching a completed form to their initial application 5/ and incorporating it by reference in subsequent applications. In establishing financial qualifications, applicants should include a copy of their recent balance sheet and full particulars concerning financing arrangements needed for the proposed facilities.

5. Details concerning the technical description and operations of the proposed facilities should be presented in a separate technical exhibit containing at least the information listed in Attachment 3. A separate exhibit should also be attached to the application concerning the frequency coordination performed for the proposed station 6/. In those cases where the submission of such information is required, the narrative environmental information specified in §1.1311 of the Rules and Regulations 7/ and/or the radiation hazard study required for transmitting earth stations by the Commission's Memorandum Opinion and Order, 38 FCC 2d 665, 704 (1972), should be submitted as separate exhibit(s).

6. In those cases where an applicant is filing a number of essentially similar applications, showings of a general nature applicable to all of the proposed stations may be submitted in the initial application and incorporated by reference in subsequent applications.

---

5/ Copies of the partnership arrangement or articles of incorporation required to complete FCC Form 430 need be attached only to the original and one copy of the application.

6/ Both the 3700-4200 MHz frequency band used by domestic satellite earth stations for reception of satellite transmissions and the 5925-6425 MHz frequency band used by earth stations for transmissions up to the satellite are shared on a co-equal basis with terrestrial microwave relay stations. Details concerning the required frequency coordination procedures are set forth in Subpart C of Part 25 of the Rules and Regulations.

7/ Subpart I of Part 1 of the Rules and Regulations sets forth the Commission's procedures for implementing the National Environmental Policy Act of 1969.

## Processing of Applications

7. Upon receipt of an application, the staff will perform a preliminary review of the application to determine whether the application is sufficiently complete to be acceptable for filing. An application will be considered deficient and will be returned to the applicant if one or more of the following circumstances occur:

(a) the application is not signed by the appropriate person specified in §1.743 of the Rules and Regulations;

(b) the application does not include the waiver required by Section 304 of the Communications Act of 1934;

(c) a certificate 8/ signed and dated by the technically qualified person responsible for preparing the technical information contained in the application is not attached;

(d) the appropriate non-refundable filing fee specified in Subpart G of Part 1 of the Rules and Regulations is not submitted with the application;

(e) the frequency coordination required by Subpart C of Part 25 of the Rules and Regulations has not been completed;

(f) a statement is not contained in the application as to whether the proposed construction is a "major" or "minor" action within the meaning of §1.1305 of the Rules and Regulations on environmental considerations; or

(g) the application is substantially incomplete with respect to the types of information normally required to be included in the application, or is otherwise not in conformance with the Commission's Rules, Regulations, or policies unless accompanied by a waiver request setting forth the nature of and the reasons for the requested waiver.

---

8/ This certificate should read as follows: "I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this application, that I am familiar with Part 25 of the Commission's Rules, that I have either prepared or reviewed the engineering information submitted in this application, and that it is complete and accurate to the best of my knowledge."

8. Upon completion of this preliminary review, a file number will be assigned and the application will be listed in the next appropriate public notice of applications acceptable for filing. A period of thirty days from the date of that notice will be allowed for any interested party to file comments or petition to deny the application. If any such pleadings are filed, the opportunity for filing oppositions and replies will be afforded in accordance with §1.45 of the Rules and Regulations. In no event will final action be taken on an application before the end of this pleading period.

9. The staff will begin processing the application at the earliest practical date and will attempt to process applications in the order of filing. The amount of time needed to process a particular application depends upon a wide variety of factors, including the completeness of the application, the nature of any issues raised by the proposed facilities, the availability of trained staff personnel, and the current workload of the processing staff. While the staff will attempt to complete the processing of routine applications not involving new or major policy issues within sixty to ninety days of their filing, it must be recognized that this goal may not be achievable in practice.

10. If, upon review of the application and supporting information, the Commission finds that the applicant is legally, financially, technically, and otherwise qualified to be a domestic satellite earth station licensee and that the public interest, convenience, and necessity would be served by a grant of the application, a construction permit will be issued for the proposed earth station facilities. The expiration date specified in the construction permit will be based on the period of time required to complete construction that is specified by the applicant. The construction permit will become automatically forfeit if the station is not ready for operation by that expiration date unless the permittee files an application (FCC Form 701) prior to the expiration date for modification of construction permit for additional time to complete construction together with a showing that failure to complete construction by that date was due to circumstances not under the control of the permittee.

11. Upon completion of construction but prior to the placement of the station into operation 9/, an application (FCC Form 403) for a license to cover the construction permit shall be filed, together with any additional showings required by the construction permit, such as the radiation level survey required for transmitting earth stations by the Commission's Memorandum Opinion and Order, 38 FCC 2d 665, 704 (1972). If no cause or circumstance has arisen since the grant of the construction permit which makes the operation of the station against the public interest, a station

---

9/ Prior to the expiration of the construction permit, the grantee may conduct over-the-air transmissions in accordance with the technical specifications set forth in the permit only for testing purposes and to verify

license will be issued by the Commission as soon as practical 10/ for a term of three years, except for developmental earth stations which are limited to one year license terms by §25.390 of the Rules and Regulations.

Simultaneous Construction Permit and License Applications

12. In those cases where the actual on-site construction of the proposed station is to be completed within a period of ninety days or less, domestic satellite earth station applicants may request the issuance of a simultaneous construction permit and license in accordance with the following terms and conditions:

(a) a properly executed FCC Form 403 must be attached to the construction permit application, and all of the parameters of the proposed earth station facilities must be specified in the application, including particulars of operation, antenna and transmitting equipment descriptions, and space segment to be accessed by the station;

(b) the application must specify the earliest date on which on-site construction may be commenced and that such construction will be completed within ninety days of the effective date of the station authorization;

(c) the effective date of the station authorization will be either the earliest date specified in the application on which construction may be commenced or the date of grant of the application, whichever is the later date, and no on-site construction shall be commenced before the effective date of the station authorization;

(d) the station authorization will be issued for a term of three years beginning on the effective date of the station authorization, except in the case of developmental authorizations which are limited to a one year term by §25.390 of the Rules and Regulations;

---

9/ (continued)

compliance of the completed facilities with the construction permit, provided that prior, written notification of such transmissions is given to the Engineer in Charge of the appropriate Commission field office listed in §0.121(a) of the Rules and Regulations, with a copy to the Common Carrier Bureau, 1919 M Street N.W., Washington D.C. 20554.

10/ A request for temporary authority to operate the station until the station license is issued may be attached to the application for license to cover construction permit if immediate operating authority is needed.

(e) the station authorization shall be automatically forfeit if the station is not ready for operation within ninety days of the effective date of the station authorization, unless an application for modification of construction permit for additional time to complete construction (FCC Form 701) is filed by that date together with a showing that failure to complete construction within ninety days of the effective date of the station authorization was due to factors not under the control of the applicant; and

(f) the station shall not be deemed to be ready for operation until the grantee certifies in writing to the Commission that the station has been constructed exactly in accordance with the technical parameters and the terms and conditions specified in the station authorization, with a copy to the Engineer in Charge of the appropriate Commission field engineering office specified in §0.121 of the Rules and Regulations, and until any additional showings that may be required prior to the commencement of actual operations, such as the radiation level survey required by the Commission's Memorandum Opinion and Order on reconsideration in Docket No. 16495, 38 FCC 2d 665, 704 (1972), are submitted to the Commission.

## Special Temporary Authorizations

13. Pursuant to Section 309(c)(2)(G) of the Communications Act, the Commission may issue special temporary authorizations for new radio operations only

(a) for a period not to exceed thirty days where no application for regular operation is contemplated, or

(b) for a period not to exceed sixty days pending the filing of an application for regular operation

without the issuance of a public notice and the thirty day comment period required by Section 309(b). This requirement applies *inter alia* to requests for temporary authority to operate a new domestic satellite earth station at a fixed location, a previously authorized transportable earth station at a new location, or an existing earth station in a new

manner 11/ that requires additional frequency coordination. These limitations do not apply, however, if the thirty day public notice is given or if the request is for a temporary minor change to the authorized operations of an earth station which, if requested on a regular basis, would not require public notice pursuant to Section 309(c)(1).

14. Applications for special temporary authorizations should be made by letter setting forth full particulars of the proposed temporary operations, including all frequency coordination data. Such requests should be filed in duplicate at least ten days prior to the scheduled commencement of the proposed operations. Frequency coordination may be effected verbally for special temporary authorizations but such authorizations will be issued subject to the conditions that no harmful interference be caused to any other lawfully operated radio station and that operations cease immediately upon notice of harmful interference. The requirement for frequency coordination may be waived for special temporary authorizations of receive-only earth station operations if the applicant waives all rights to protection from interference from other radio stations for such temporary receive-only operations.

## Developmental Authorizations

15. Developmental authorizations for domestic satellite earth station operations may be issued under §25.390 of the Rules and Regulations for:

(a) the development of new techniques which give promise of improvement in the domestic satellite service;

(b) the development and testing of equipment intended for use in the domestic satellite service;

(c) path loss tests necessary to the location of newly proposed earth stations.

Applicants proposing such types of developmental earth station operations should file applications under Part 25 rather than Part 5 of the Rules and Regulations 12/. Developmental domestic satellite earth station applications will be handled in essentially the same manner as applications for regular domestic satellite earth station authorizations, except where differences are required by §25.390 of the Rules and Regulations.

---

11/ For example, with an increased EIRP, at a lower minimum elevation angle, or in a portion of the frequency band for which frequency coordination was not previously effected.

12/ §5.251(b) defining elegibility for Experimental(Developmental) authorizations provides that "Applicants eligible for authorizations in an established service, and seeking to develop operational data or techniques toward the improvement or extension of that service, shall conduct such projects under the developmental rules of the established service."

## Conclusion

16. The guidelines set forth in this public notice are being issued at this time to provide minimum standards for domestic satellite earth station applications with the view towards a more efficient and orderly application processing procedure. While they are based on the past experience of the processing staff, it must be recognized that additional information or requirements may be necessary with respect to any particular application. Moreover, as additional experience is gained, revisions to or clarifications of these guidelines may be required and, if of general applicability, may be made through the issuance of additional public notices. The staff is also in the process of preparing a Notice of Proposed Rule Making entailing an overall revision of Part 25 of the Rules and Regulations governing satellite communications with the view *inter alia* towards simplifying processing procedures to the extent practicable for domestic satellite earth station applications, including those for receive-only stations.

17. Action by the Commission August 1, 1975. Commissioners Wiley (Chairman), Lee, Reid, Hooks, Quello, Washburn and Robinson.

-FCC-

Attachments - 3

-FCC-

Attachment 1

# PUBLIC NOTICE

Federal Communications Commission ■ 1919 M Street, NW. ■ Washington, D.C. 20554

For recorded listing of releases and texts call 632-0002

For general information call 632-7260 18850

February 26,1974 - C

REQUESTS FOR WAIVER UNDER SECTION 319 (d)

BY DOMESTIC SATELLITE APPLICANTS

In the domestic satellite field the Commission has received an unusual number of requests for waiver, pursuant to Section 319 (d) of the Communications Act, to permit procurement or commencement of construction prior to action on the applications for construction permits. Recently, we have been requested to grant such a waiver before any application was filed.

Domestic satellite licensees, applicants and potential applicants are reminded that a Section 319 (d) waiver is an extraordinary procedure. Such waiver is not to be regarded as a routine substitute for processing of and action on an application in due course, whenever an applicant desires to proceed at its own risk. Rather it is available in the exceptional situation where the public interest in expedition overrides considerations of orderly procedure and the policy underlying the general statutory requirement for a prior construction permit.

While the Commission has been very liberal with the first round of domestic satellite applications, applicants are requested to make every effort to file new applications in time to permit processing and Commission action prior to the anticipated time for procurement and/or commencement of construction. Any request for waiver pursuant to Section 319 (d) should show why the public interest requires expedition and why it was not possible to file the application at an earlier date. A request for a Section 319 (d) waiver will not be entertained prior to the filing of an application for a construction permit for the facility involved.

- FCC -

Attachment 2

PUBLIC NOTICE

Federal Communications Commission ■ 1919 M Street, N.W. ■ Washington, D.C. 20554

50233

C

May 14, 1975

DOMESTIC SATELLITE EARTH STATION
CONSTRUCTION PERMIT APPLICATIONS

In issuing construction permits and licenses for domestic satellite earth stations, the Commission specifies in the station authorization the "range of azimuths of center of main lobe of radiation with respect to true north" over which the earth station may be operated. This range of azimuths corresponds to the range of satellite orbital locations for which frequency coordination with terrestrial microwave stations has been successfully completed in accordance with Subpart C of Part 25 of the Rules and Regulations.

The Commission has recently become concerned with the fact that certain domestic satellite earth station applicants have been performing frequency coordination for a very limited portion of the geostationary arc (e.g. a 20° range of satellite orbital locations as compared to the range of 70° or more in satellite longitude which is potentially useable by United States domestic satellites). Moreover, it also appears that such earth station antennas have been constructed with mountings which can be physically steered only over such a limited range of azimuths and elevation angles without extensive alterations to the antenna mounting.

While Part 25 allows frequency coordination with terrestrial microwave stations over a limited portion of the geostationary arc visible at the proposed earth station site and/or over a portion of the frequency band(s) to be utilized by the station, domestic satellite earth station applicants are hereby given notice that the Commission may not be able to accomodate such operational restrictions at particular earth stations in making or modifying domestic satellite orbital location assignments. Although the Commission will attempt to minimize the negative consequences on the operations of any domestic satellite earth station that may be authorized with such

operational restrictions, the applicant will be required to accept any consequences that could result from such restrictions on operational flexibility. For this reason, domestic satellite earth station applicants are urged to perform frequency coordination with terrestrial microwave stations over as wide a range of satellite orbital locations and frequency as possible to maximize the operational flexibility of their proposed earth stations. The earth station antenna mounting must be physically capable of movement over the entire range of the geostationary satellite arc visible at the earth station for which frequency coordination has been performed. Moreover, we urge that the antenna be capable of movement over the entire orbital arc potentially useable by United States domestic satellites whether or not frequency coordination has been performed over the entire arc.

Accordingly, domestic satellite earth station applicants who do not perform frequency coordination over the entire range of satellite orbital locations from about 70° West to about 135° West suitable for use by domestic satellites or the entire 3700-4200 MHz and/or 5925-6425 MHz frequency bands should include in their applications a statement why such coordination is not practical. Applicants should also include in their applications a description of the physical mounting and steering capabilities of the proposed earth station antenna, including the range of azimuths and elevation angles over which the antenna can be steered. In the event that the range over which the antenna can be physically steered is less than the range over which frequency coordination has been effected, a justification for such a limitation should be included in the application.

-FCC-

Attachment 3

TECHNICAL INFORMATION REQUIREMENTS FOR
DOMESTIC SATELLITE EARTH STATION APPLICATIONS

Site Availability

The proposed earth station site should be identified both by geographic coordinates and by the city, county or parish, and state. The applicant should also state how its right to use the site has been secured, e.g. by ownership or option to buy, by lease or option to lease (state term of lease) etc.

If the proposed station is to be located on land owned by the Federal Government, the procedures set forth in §1.70 of the Rules and Regulations must be followed. Applicants should also be aware of §§25.203(f) and (g) conerning the radio quiet zones in the Colorado and West Virginia areas.

Overall Technical Description

The applicant should present a general, overall description of the proposed station facilities and operations in sufficient detail to convey a basic understanding of the communications services to be provided through the proposed station. The major structures and equipment comprising the station should be identified, and the application should include a functional block diagram of the station equipment and a sketch of the site layout drawn to approximate scale.

The applicant should also describe the initial and potential communications capacity of the proposed station in terms of the numbers and types of channels to be provided through the station. (Note that this information does not replace the information that common carriers are required by Part 63 of the Rules and Regulations to include in their applications for Section 214 authorizations.)

Applicants should also specify the period of time required for the completion of construction (or the equivalent type of information required in simultaneous construction permit and license applications), and should state the estimated cost of the proposed earth station facilities by major component, e.g. land, buildings, transmitting and receiving equipment, antennas, channel equipment, engineering and installation, etc.

Points of Communication

The applicant should identify the space segment to be accessed by the proposed station and the other earth station(s) with which the proposed station is to communicate.

If the proposed earth station is to transmit to a satellite not authorized to the earth station applicant, a copy of approval of the space segment operator for such access should be included in the application. Earth station applicants proposing to receive program distribution material not owned or originated by the earth station applicant should include a copy of the approval of the programming owner for the reception and use of such material. Finally, earth station applicants proposing the reception of satellite signals not originated by the earth station applicant and not part of a program distribution network should also include a copy of the approval of the space segment operator for the reception and use of the signals received from its satellite, in addition to the approval of the program owner. The terms and conditions of such approvals should be clearly indicated.

## Particulars of Operation

Licenses for domestic satellite earth stations specify the assigned frequencies (or transponder frequency plans where multiple r.f. carriers access the transponder), polarization, emission designators, and, in the case of transmitting earth stations, maximum main beam EIRP's and EIRP densities per 4 kHz. This information should be specified in the construction permit application, together with the modulation characteristics and baseband configuration for each type of r.f. carrier to be transmitted or received at the proposed earth station.

It should be noted in this regard that the number of frequencies authorized at a domestic satellite earth station is determined by the scope of the frequency coordination performed for the station. A greater number of frequencies are normally authorized to a station than the number of frequencies to be actually utilized at the station in order to allow flexibility to accomodate changes in the transponder usage plans of the space segment operator. Thus, for example, a domestic satellite earth station cleared across the entire frequency band on a co-channel basis may be assigned 12 or 24 frequencies (depending on the satellite to be employed) for television signals while a station cleared over only half of the band may be assigned only 6 or 12 frequencies, even though only a single television signal would be transmitted or received at both stations.

## Transmitting Equipment

The earth station applicant should specify the number and type of the transmitters to be installed at the station, together with the output power and frequency tolerance of each type of transmitter.

Antenna Facilities

The following should be provided for each antenna to be installed at the proposed earth station:

(a) a brief description of the antenna, including manufacturer and model, diameter and type of feed;

(b) a description of the antenna mounting, including the range of azimuth and elevation over which the antenna can be steered;

(c) antenna gain patterns and a statement as to whether the antenna performance conforms to the standards specified in §25.209 of the Rules and Regulations;

(d) the frequency range over which the station is capable of transmitting and/or receiving (may be larger than the frequency range for which the earth station was coordinated);

(e) the transmit and/or receive main beam antenna gain and 3 dB full beamwidth (specify frequency at which each parameter is measured);

(f) polarization capability of the antenna;

(g) receiving system noise temperature (specify frequency and antenna elevation angle at which it is measured); and

(h) the elevation of the antenna base above mean sea level, the height of the antenna center line above the antenna base, and the maximum antenna height above the antenna base.

# PUBLIC NOTICE

Federal Communications Commission ■ 1919 M Street, N.W. ■ Washington, D.C. 20554

Report No. I-482

-C-
July 5, 1978

IMPROVED AUTHORIZATION PROCEDURE
FOR DOMESTIC SATELLITE EARTH STATIONS.

2625

The Common Carrier Bureau has begun to issue radio station authorizations for domestic satellite earth stations that are printed by computer. This computer system has been designed to foster more efficient application processing and record keeping.

New domestic earth station authorizations will be granted on FCC Form 488 which contains essentially the same data as the previous manually typed authorizations on FCC Forms 456-A through 456-L with the additional listing of receive frequency bands on transmitting earth station authorizations. In this regard, it should be noted that authorizations for television (36000F9 emission designator) receive-only earth stations will no longer list specific transponder frequencies in the particulars of operation, but the frequency band for which coordination was effected with terrestrial microwave stations, since the authorized receive frequencies are fixed by satellite transponder design.

Because of computer limitations, special provisions relating to frequency use and general provisions setting forth the terms and conditions under which the authorization is issued will be specified on the computer printed FCC Form 488 only by code number. A separate FCC Form 488-A will be attached, which lists the text of the special or general provision corresponding to each of the code numbers printed on the authorization. The only special and general provisions listed on FCC Form 488-A which apply to a particular station authorization are those whose code numbers are printed on the authorization (FCC Form 488) itself.

For earth stations already in the data base, i.e. those for which the original construction permit application was filed after March 1, 1978, modifications and renewals will be granted by simply re-issuing the entire authorization as modified or renewed under the new application file number. The same procedure will also be used for earlier filed applications as the earth stations are entered into the data base.

In addition, the present practice of issuing a covering Order and Authorization for routine earth station grants will be discontinued, and a weekly public notice of actions taken will be issued instead. Covering orders will be issued only in contested cases or where the application raises an issue or precedent on which discussion is warranted for the guidance of other applicants.

-FCC-

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION

# RADIO STATION AUTHORIZATION

CONSTRUCTION PERMIT AND LICENSE

NAME: TELECABLE OF BLOOMINGTON-NORMAL CORP.

CALL SIGN: WH60

FILE NO.: 000576-DSE-P/L -78

DOMESTIC FIXED SATELLITE SERVICE
FIXED EARTH STATION

DATE OF GRANT: JULY 7, 1978

| LOCATION OF STATION: | | | LATITUDE | LONGITUDE |
|---|---|---|---|---|
| NORMAL | ,MCLEAN | ,ILLINOIS | 40 29 43 N | 89 0 11 W |

SUBJECT TO THE PROVISIONS OF THE COMMUNICATIONS ACT OF 1934, THE COMMUNICATIONS SATELLITE ACT OF 1962, SUBSEQUENT ACTS AND TREATIES, AND ALL PRESENT AND FUTURE REGULATIONS MADE BY THIS COMMISSION, AND FURTHER SUBJECT TO THE CONDITIONS AND REQUIREMENTS SET FORTH IN THIS PERMIT AND LICENSE, THE GRANTEE IS AUTHORIZED TO CONSTRUCT, USE AND OPERATE THE RADIO FACILITIES DESCRIBED BELOW FOR RADIO COMMUNICATIONS FOR THE TERM BEGINNING JULY 7, 1978 (3 A.M. EASTERN STANDARD TIME) AND ENDING JULY 7, 1981 (3 A.M. EASTERN STANDARD TIME).
THE REQUIRED DATE OF COMPLETION OF CONSTRUCTION IS OCTOBER 7, 1978.

1. PARTICULARS OF OPERATIONS

| FREQUENCY (MHZ) AND POLARIZATION | EMISSION | MAXIMUM E.I.R.P. | MAXIMUM E.I.R.P. DENSITY | SPECIAL PROVISIONS (REFER TO FCC FORM 488-A.) |
|---|---|---|---|---|
| 3700.000- 4200.000 H,V | 36000F9 | --- | --- | 1000 , 1500 |

RANGE OF AZIMUTHS OF CENTER OF MAIN LOBE
OF RADIATION WITH RESPECT TO TRUE NORTH: 152.1 TO 242.2 DEGS. AT 4 GHZ

RANGE OF ANTENNA ELEVATION ANGLE: 39.2 TO 20.4 DEGS. AT 4 GHZ

MAXIMUM E.I.R.P. TOWARD THE HORIZON: (NOT APPLICABLE TO RECEIVE-ONLY OPERATIONS)

RANGE OF SATELLITE LONGITUDES: 70.0 TO 140.0 DEGS. AT 4 GHZ

RECEIVING SYSTEM NOISE TEMPERATURE: 142 DEGS. K AT 20.04 DEGS. ELEVATION AT 4000 MHZ



FEDERAL
COMMUNICATIONS
COMMISSION

# • STANDARD CONDITIONS •

## * THIS RADIO STATION AUTHORIZATION IS SUBJECT TO THE FOLLOWING STANDARD CONDITIONS:

This radio station authorization is issued on the grantee's representations that the statements contained in the applications of the grantee for these facilities are true and that the undertakings described in those applications, so far as they are consistent with this authorization, will be carried out in good faith.

This radio station authorization shall not be construed in any manner as a finding by the Commission on the question of marking or lighting of the antenna system should future conditions require. The grantee expressly agrees to install such marking or lighting as the Commission may require in the future under the provisions of Section 303(q) of the Communications Act of 1934.

Neither this radio station authorization nor the right granted by this authorization shall be assigned or otherwise transferred to any person, firm, company or corporation without the written consent of the Commission. This authorization is subject to the right of use or control by the government of the United States conferred by Section 606 of the Communications Act of 1934. Operation of this station are governed by Part 25 of the Commission's Rules and Regulations.

## IN ADDITION, THE FOLLOWING STANDARD CONDITIONS ARE APPLICABLE TO THE PARTICULAR TYPE OF RADIO STATION AUTHORIZATION SPECIFIED IN THE CAPTION ON THE FRONT SIDE OF THIS FORM:

## • LICENSE •

**This license shall not vest in the licensee any right to operate this station nor any right in the use of the frequencies designated above beyond the term of this license, nor in any other manner than authorized above.**

## • CONSTRUCTION PERMIT •

Upon completion of station construction, the permittee shall demonstrate to the Commission that all the terms, conditions and obligations set forth in the applications and in this permit have been fully met, and shall apply for a radio station license. Upon such sowing and application, and upon a finding by the Commission that since the granting of this permit no cause or circumstances has arisen which, in the judgment of the Commission, makes the operation of the station against the public interest, a radio station license will be issued by the Commission for the operation of the station. This permit shall not vest in the permittee any right to operate the the station, nor any right to a license authorizing the use of the particular frequencies and emissions, or the particular longitudes in the geostationary orbit, or the amount of power, or the time of operation specified above. The Commission, in issuing this permit, reserves the right to assign whatever frequencies and emissions, orbital locations, power and convenience or necessity. The terms of that license as to frequencies, emissions, orbital locations, power, time of operation and scope of communication are expressly made subject to the exercise of this reserved right. This permit shall become automatically forfeit if this station is not ready for operation within the time specified below, unless prior to the expiration of this permit the Commission shall have granted an extension of time. Upon proper showing made to it by the permitee prior to the expiration of this permit, the Commission may grant an extension if it finds that the permittee was prevented from completing the construction of this station by causes not under permittee's control.

## • CONSTRUCTION PERMIT/LICENSE •

This simultaneous construction permit and license is issued pursuant to paragraph 15 of the Commission's Declaratory Ruling (55 FCC 2d 656) adopted July 30, 1975, and, in particular, is subject to the following terms and conditions:

(a) This authorization shall be automatically forfeit if the station is not ready for operation by the required date of completion of construction specified on the reverse side of this form, unless an application for modification of construction permit for additional time to complete construction is filed by that date together with a showing that failure to complete construction by the required date was due to factors not under control of the grantee.

(b) The station shall not be deemed to be ready for operation until the grantee certifies in writing to the Commission that the station has been constructed exactly in accordance with the technical parametersand terms and conditions specified in this authorization, with acopy to the Engineer in Charge of the appropriate Commission field office specified in Section 0.121 of the Rules and Regulations.

This license shall no! vest in the licensee any right to operate this station nor any right in the use of the frequencies designated above beyond the term of this license, nor in any other manner than authorized above.

FCC Form 488
March 1978

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION

# RADIO STATION AUTHORIZATION

CALL SIGN: WH60

FILE NO.: 000576-DSE-P/L -78

2. POINTS OF COMMUNICATIONS

THE FOLLOWING SPACE STATIONS LOCATED IN THE GEOSTATIONARY SATELLITE ORBIT:
KS30 RCA SATCOM I
KS31 RCA SATCOM II

3. TRANSMITTING EQUIPMENT

(NOT APPLICABLE TO RECEIVE-ONLY OPERATIONS)

4. ANTENNA FACILITIES

NO.1 5.0 METER CASS ANTENNA SCIENTIFIC ATLANTA MODEL 8008A
GAIN: 44.3 DBI AT 4 GHZ MAXIMUM ANTENNA HEIGHT(AMSL): 237.4 METERS SITE/ELEVATION: 231.6 METERS

5. REMOTE CONTROL POINT: NONE

THIS AUTHORIZATION IS SUBJECT TO THE ADDITIONAL NUMBERED SPECIAL PROVISIONS AND THE FOLLOWING NUMBERED GENERAL PROVISIONS SPECIFIED ON THE ATTACHED FCC FORM 488-A.

| | | | |
|---|---|---|---|
| ( 1) | 2000 | ( 6) | 2210 |
| ( 2) | 2010 | ( 7) | 2500 |
| ( 3) | 2020 | ( 8) | 2510 |
| ( 4) | 2100 | ( 9) | 2800 |
| ( 5) | 2200 | | |

PAGE 2 OF 2

FEDERAL
COMMUNICATIONS
COMMISSION

# • STANDARD CONDITIONS •

## * THIS RADIO STATION AUTHORIZATION IS SUBJECT TO THE FOLLOWING STANDARD CONDITIONS:

This radio station authorization is issued on the grantee's representations that the statements contained in the applications of the grantee for these facilities are true and that the undertakings described in those applications, so far as they are consistent with this authorization, will be carried out in good faith.

This radio station authorization shall not be construed in any manner as a finding by the Commission on the question of marking or lighting of the antenna system should future conditions require. The grantee expressly agrees to install such marking or lighting as the Commission may require in the future under the provisions of Section 303(q) of the Communications Act of 1934.

Neither this radio station authorization nor the right granted by this authorization shall be assigned or otherwise transferred to any person, firm, company or corporation without the written consent of the Commission. This authorization is subject to the right of use or control by the government of the United States conferred by Section 606 of the Communications Act of 1934. Operation of this station are governed by Part 25 of the Commission's Rules and Regulations.

## IN ADDITION, THE FOLLOWING STANDARD CONDITIONS ARE APPLICABLE TO THE PARTICULAR TYPE OF RADIO STATION AUTHORIZATION SPECIFIED IN THE CAPTION ON THE FRONT SIDE OF THIS FORM:

## • LICENSE •

This license shall not vest in the licensee any right to operate this station nor any right in the use of the frequencies designated above beyond the term of this license, nor in any other manner than authorized above.



## • CONSTRUCTION PERMIT •

Upon completion of station construction, the permittee shall demonstrate to the Commission that all the terms, conditions and obligations set forth in the applications and in this permit have been fully met, and shall apply for a radio station license. Upon such sowing and application, and upon a finding by the Commission that since the granting of this permit no cause or circumstances has arisen which, in the judgment of the Commission, makes the operation of the station against the public interest, a radio station license will be issued by the Commission for the operation of the station. This permit shall not vest in the permittee any right to operate the the station, nor any right to a license authorizing the use of the particular frequencies and emissions, or the particular longitudes in the geostationary orbit, or the amount of power, or the time of operation specified above. The Commission, in issuing this permit, reserves the right to assign whatever frequencies and emissions, orbital locations, power and convenience or necessity. The terms of that license as to frequencies, emissions, orbital locations, power, time of operation and scope of communication are expressly made subject to the exercise of this reserved right. This permit shall become automatically forfeit if this station is not ready for operation within the time specified below, unless prior to the expiration of this permit the Commission shall have granted an extension of time. Upon proper showing made to it by the permitee prior to the expiration of this permit, the Commission may grant an extension if it finds that the permittee was prevented from completing the construction of this station by causes not under permittee's control.



## • CONSTRUCTION PERMIT/LICENSE •

This simultaneous construction permit and license is issued pursuant to paragraph 15 of the Commission's Declaratory Ruling (55 FCC 2d 656) adopted July 30, 1975, and, in particular, is subject to the following terms and conditions:

(a) This authorization shall be automatically forfeit if the station is not ready for operation by the required date of completion of construction specified on the reverse side of this form, unless an application for modification of construction permit for additional time to complete construction is filed by that date together with a showing that failure to complete construction by the required date was due to factors not under control of the grantee.

(b) The station shall not be deemed to be ready for operation until the grantee certifies in writing to the Commission that the station has been constructed exactly in accordance with the technical parametersand terms and conditions specified in this authorization, with acopy to the Engineer in Charge of the appropriate Commission field office specified in Section 0.121 of the Rules and Regulations.

This license shall not vest in the licensee any right to operate this station nor any right in the use of the frequencies designated above beyond the term of this license, nor in any other manner than authorized above.

# SPECIAL AND GENERAL PROVISIONS FOR RADIO STATION AUTHORIZATION

The radio station authorization granted on FCC Form 488 is subject to additional terms and conditions specified by code numbers on that form. The text of the special and general provisions corresponding to those code numbers is given below:

## SPECIAL PROVISIONS

- 1000 Maximum e.i.r.p. and maximum e.i.r.p. density are not applicable to receive-only operations.
- 1010 Receive frequency band. Emission designator indicates the maximum bandwidth of transmissions received at this station. Maximum e.i.r.p. and maximum e.i.r.p. density are not applicable to receive operations.
- 1500 Carrier frequency modulated by a composite television signal consisting nominally of a video carrier with a baseband of 10 Hz or 15 Hz to 4.25 MHz and an audio subcarrier at 6.2 or 6.8 MHz with a baseband of 20 Hz to 15 KHz.
- 1510 Carrier frequency modulated by a television signal consisting of a National Television System Committee (NTSC) standard color video carrier with a baseband of 4.2 MHz, an audio subcarrier of 6.8 MHz with a baseband of 15 KHz, and a four-phase 1.79 megabits per second, phase shift modulated subcarrier at 5.5 MHz.
- 1900 Authority is granted to transmit any number of r.f. carriers with the specified parameters on any discrete frequencies within this band in accordance with the other terms and conditions of this authorization, subject to any additional limitations that may be required to avoid unacceptable levels of inter-satellite interference.

## GENERAL PROVISIONS

- 2000 The hours of operations of this station are not limited.
- 2010 This authorization is issued pursuant to the Commission's Second Report and Order adopted June 16, 1972 (35 FCC 2d 844) and Memorandum, Opinion and Order adopted December 21, 1972 (38 FCC 2d 665) in Docket No. 16495 and is subject to the policies adopted in that proceeding.
- 2020 The use of the small diameter earth station antenna facilities is authorized pursuant to the Commission's decision in American Broadcasting Companies et al, 62 FCC 2d 901 (1976).
- 2030 The authority granted by this station authorization is limited to the operation of the radio facilities described above, and does not include any authority under Section 214 of the Communications Act to establish channels of communication or to provide communications services for hire.
- 2100 These facilities shall be used by the grantee solely for the purpose of providing program reception services for its cable television system operations or providing such services on a nonprofit basis to other cable television systems operated by affiliated companies under common corporate control with the grantee. This station shall not be used to provide program reception service to non-affiliated cable television systems or other entities for the rendition of communications services for hire unless and until the grantee has applied for and been granted the appropriate modification of the authority granted herein.
- 2110 These facilities shall be used by the grantee solely for the purpose of receiving program material to be used by non-commercial broadcast licensee(s) in connection with the operation of the noncommercial broadcasting station(s). This station shall not be used for other purposes or for hire unless and until the grantee has applied for and been granted the appropriate modification of the authority granted herein.
- 2200 These facilities shall be used for the reception of only such programming material that the grantee has been authorized to receive and use by the owner of the programming material.
- 2210 The grantee is authorized to add, delete or change channels of program material received from the satellites specified in Section 2 of this authorization without further application or notification to the Commission, provided (a) that carriage of such program material is authorized pursuant to the Commission's rules, regulations and policies governing the terrestrial system(s) used to distribute this material to the end subscribers, and (b) that such earth station operations are consistent with the technical parameters specified in this authorization.
- 2300 Authority is granted to operate this station by remote control provided that: (1) the parameters of the transmissions of this station monitored at the remote control point, and the operational functions sufficient to insure that the operations of this station are in full compliance with the station authorization at all times; (2) upon detection by the grantee, or upon notification from the Commission, of a deviation of the operation of this station shall be immediately suspended until the deviation is corrected, except that transmissions concerning the immediate safety of life or property may be conducted for the duration of such emergency; and (3) the grantee shall have available at all times the technical personnel necessary to perform the technical servicing and maintenance of this station expeditiously.

## GENERAL PROVISIONS (Cont'd)

• 2500 With respect to potential co-channel interference to or from terrestrial microwave radio stations: receive frequency band(s) listed in Section 1 of this authorization have been cleared for transmissions from and transmit frequency band(s) listed in Section 1 have been cleared for transmissions to satellites located in the portion of the geostationary satellite orbit specified in Section 1 for the emissions designated in that Section.

• 2510 Waiver of Section 25.203(e) of the Commission's Rules and Regulations is granted for the beam intersections listed in the application(s) for this facility.

• 2600 No protection from interference caused by other radio stations will be provided for these operations.

• 2610 No harmful interference will be caused by the operations of this station to other lawfully operated radio stations and operation of this station will be ceased immediately upon notifications of such harmful interference.

• 2800 The grantee shall maintain on file with the Commission a current listing of each cable television system served through this station, with any additions, deletions, or modifications to this list notified within 10 days of such changes, including the following information for each such cable television system(s): (a) the name of the cable television system operator and the city or area it serves; (b) the affiliation, if any, of the cable television system operator with the grantee; (c) the date service was commenced; (d) identification of the terrestrial facilities utilized to interconnect this earth station with the head-end of the cable television system being served.

• 2810 The grantee shall maintain on file with the Commission a current list or plan of the precise frequencies in actual use at this station, specifying for each such frequency: the r.f. center frequency, polarization, emission designator, EIRP (dBW), EIRP density (dBW/4 KHz), and receiving earth station(s). This list or plan may be submitted either on a station-by-station basis or on a system-wide basis, and shall be updated within seven days of any changes in frequency usage at this station. Temporary usage of frequencies for periods of less than seven days need not be notified to the Commission if accurate station records are maintained of the times and particulars of such temporary frequency usage.

• 2820 Upon completion of construction, but prior to the operation of this station, the grantee shall conduct the radiation level survey required by paragraph 95 of the Commission's _Memorandum, Opinion and Order_ adopted December 21, 1972, in _Docket No. 16495_ (38 FCC 665, 704) and submit this survey to the Commission.

• 2900 This developmental authorization is issued pursuant to Section 25.390 of the Commission's Rules and is subject to change in any of its terms or to cancellation in its entirety at any time, upon reasonable notice but without hearing, if, in the opinion of the Commission, circumstances should so require. The rendition of communications services for hire by means of these facilities is prohibited.

# TELEVISION PARAMETERS FOR ALASKAN SATELLITE SERVICE

G.W. Beakley
Manager - Engineering
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

# TELEVISION PARAMETERS FOR ALASKAN SATELLITE SERVICE*

Abstract

Two different satellite television services are being implemented by RCA Americom and RCA Alascom for the State of Alaska. They are two channel per transponder service from the lower 48 to the large communities in Alaska and one channel per transponder to the small communities in the Bush. The former service is to allow real-time television to be broadcast in the state. Initial selection of the two channels will be made at any one time from the various network services. The two channels are transmitted on one transponder and received by earth stations in the large communities. The channels will then be relayed to the appropriate television stations for taping and/or rebroadcast. This service is expected to be offered for approximately 16 hours a day. The remaining 8 hours of transponder time are to be used for television to the Bush. This television signal is transmitted from one of the large earth stations in the U.S. and received by the small, inexpensive earth stations in the Bush. This paper discusses the parameter and cost tradeoffs that were made in establishing the Alaskan satellite service.

## Introduction

Before satellite communication became practical, television broadcasts in Alaska were typically delayed from 1 day to 2 weeks from the time of the broadcasts in the contiguous 48 states. This delay represented distribution time for the broadcast video tapes. The satellite television service described in this paper allows "real time" broadcast in Alaska of up to 2 network services. In addition, it also allows television to be received in remote locations where television service had previously been impractical.

In order to minimize the space segment costs (transponder rental) it was decided that one transponder would be used for service to the cities and to the Bush. Since the expected number of Bush Earth Stations could be 100 or more, it was necessary for the cost of the Bush terminals to be low. Also, since more than one television channel was needed in the cities, the objectives became somewhat incompatible. The incompatibility was solved by establishing two services to be time shared on the satellite. One service was a Bush service which could be received by the small earth stations in the remote areas as well as the large earth stations in the cities. The other service was a two channel per transponder service that could be received by the large earth stations. These services can be easily discussed as separate entities.

The satellite that is used for Alaskan television service is RCA spacecraft F2, which is located at 119°W and has 6 transponders with a 3° tilt toward Alaska. The EIRP (effective isotropically radiated power) used in this report are computer generated based on values measured on the test range and verified at earth stations throughout the U.S.

## Bush Service

The Alaskan Bush Service began with approximately 24 receive earth stations. The number of earth stations could eventually be one hundred or more. The initial design considered one hundred sixty possible Bush terminal locations. These earth stations have antenna elevation angles as low as 5° with the horizon and as high as 26° with the horizon. The EIRP ranges from a low of 33.8 dBw (26 dBw on a non-Alaskan beam) and a high of over 36 dBw (34.2 dBw on a non-Alaskan beam) in these 160 locations. The selection of the system design was a trade-off of the following parameters: picture and sound quality, cost of service, reliability of the service, and the availability of the equipment. The picture quality was specified by a number of parameters. Principal of these were that the CCIR weighted signal-to-noise ratio

*Reprinted from Electro '77, New York, April 19-21, 1977.

(SNR) be better than 43 dB. Furthermore, no impulse noise or video distortion was to be visible at any of the earth stations under normal operating conditions.

Experimentation began with purchase of a standard earth station television modulator and demodulator. These devices were connected at 70 MHz with added white noise. The purpose was to determine the range of carrier-to-noise density, C/kT, and peak video deviation, $\Delta F$, that would be acceptable for the Alaskan bush service. Fig. 1 shows curves of C/kT versus deviation and IF bandwidth for the point at which the impulse noise is just noticeable in EIA color bars. It is clearly seen from Fig. 1[1] that there is an optimum range of deviation and bandwidth for minimum C/kT operation.

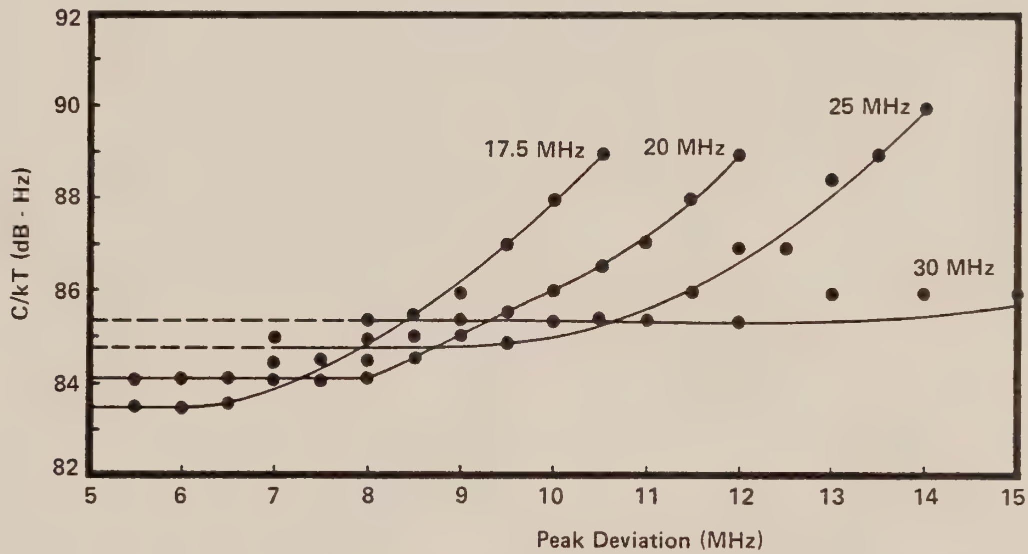



**Figure 1. Just Noticeable Impulse Distortion vs. Peak Deviation for Different IF Filters**

The point where impulse noise is just noticeable in the EIA color bars is a subjective test[2]. Nevertheless most expert viewers agree on just noticeable impulse distortion (JND) within a carrier-to-noise ratio (CNR) of one-half dB. It should be noted that the FM threshold is sometimes defined as the CNR for which the measured SNR versus CNR curve is one dB down from a straight line projection. For example, the threshold for the discriminator of Fig. 2 would be about 8 to 8.5 dB. Notice from Fig. 1 that the CNR for JND using the same discriminator under the same conditions is about 11.5 to 12.0 dB. The discrepancy is due to the fact that impulse noise is easier for the eye to detect than for the rms meter to detect. Since impulse noise is the foremost degrading effect in the picture it is felt that JND (or objectively, number of spikes/sec) should determine the minimum operating point in an FM system and not the SNR-CNR threshold. The use of EIA color bars is a difficult test. Nevertheless, provisions have to be made for programs with highly saturated colors, e.g. typical children's programming.

In addition to JND, one must consider the video distortion generated by these bandwidth and deviation combinations. It was shown[1] that the video distortion for any of the minimum C/kT combinations satisfied the following video distortion conditions:

short time waveform distortion, SD $\leq$ 10%

luminance-chrominance delay, LCD $\leq$ 50 ns

differential gain, DG $\leq$ 10%

differential phase, DP $\leq 5^\circ$

It should be noted that the inclusion of an audio subcarrier causes impulse noise to be noticed at a higher C/kT than shown in Fig. 1[2]. Furthermore, the deviation range for minimum C/kT is lower for a given bandpass filter when an audio subcarrier is used than when it is not. Also, as expected, a given video distortion level occurs at a lower deviation for the same IF filter when a subcarrier is used.

A computer program was written to allow a number of alternative television transmission designs to be considered for the Alaskan Bush application. The EIRP's to each village were generated assuming a satellite position of 119°W for RCA spacecraft F2. For transponder No. 15 (4 GHz down), a path loss of 197.0 dB (free space plus normal atmospheric loss) was assumed for all locations. In addition, 0.2 dB was subtracted to account for uplink thermal noise and interference. The G/T was computed using a gain of 43.4 dB for a 4.5 meter antenna and 48.4 dB for an 8 meter antenna. The system noise temperature, $T_S$, was computed using the elevation angle for each village by the formula:

$$T_S = T_R + T_A$$

where $T_R$ is the noise temperature of the LNA and $T_A$ ranges from 66K for a 5° elevation angle to 40 K for a 30° elevation angle.

The computer program allows input of the minimum SNR, desired video deviation, minimum CNR margin, and number of dB of threshold extension, if any. The program then assigns the appropriate antenna and LNA to each village from two possible antenna sizes (4.5m or 8m) and four possible receiver noise temperatures (190 K, 130 K, 80 K, and 45K).

A number of interesting possibilities arise. For example, consider the transmission of the television signal with a peak deviation of 7 MHz and sound on another transponder. The 160 earth stations can be configured as shown in Table 1, section a. The margin above JND is the CNR margin above the just noticeable distortion due to threshold or truncation impulse noise. This means that a loss of 1.8 dB in CNR would cause the onset of just noticeable impulse noise at some of the Bush earth stations. Other earth stations would have to lose up to 3.8 dB before the onset of impulse noise. The margin before receiving an unsatisfactory[1] picture is approximately 4 dB plus the margin above JND. Therefore, under normal circumstances it is unlikely that the picture will become "unwatchable".

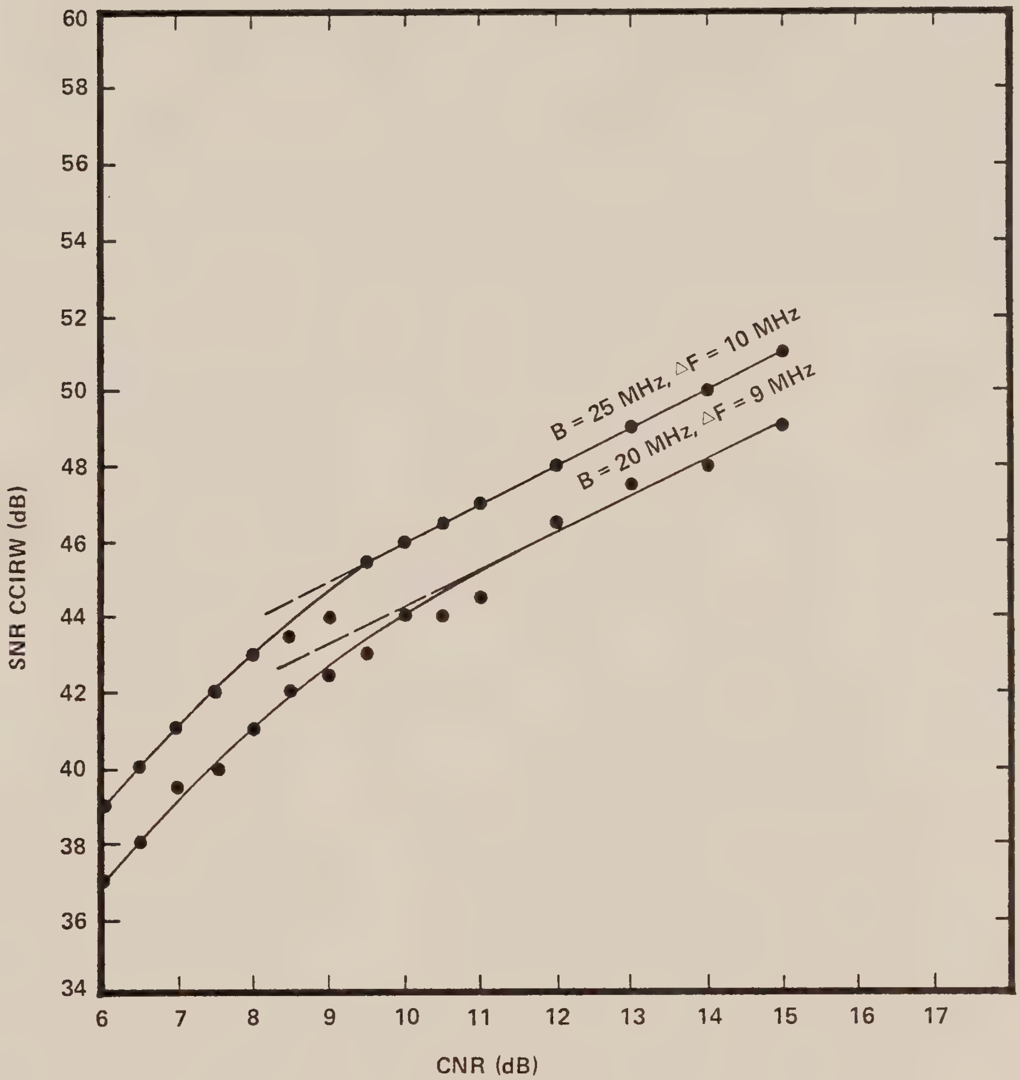



Figure 2. C.C.I.R. Weighted Signal-to-Noise Ratio vs. Carrier-to-Noise Ratio

Consider now the use of a peak deviation of ±8 MHz, a 20 MHz IF filter and sound on another transponder. The resulting configuration of Bush Earth Stations is shown in Table 1, section b. Note that increasing the deviation to ±8 MHz essentially yields a 1.1 dB higher SNR at a cost of a 0.6 dB lower CNR margin above JND. It has been estimated that the CNR margin needed for an availability of 0.99 (an average of 1 hour and 40 minutes of degraded signal per week) is 1.2 dB for a 190 K LNA and 1.8 dB for a 45 K LNA at an elevation angle of 10°[3]. Based on this estimate it is concluded that the availability of a signal unimpaired by impulse noise is about 0.99 or more for this earth station configuration.

If it were desirable to increase the SNR to a minimum of, for example, 49 dB, the deviation could be increased to ±10 MHz. The sound could be included at 70 mV on a 6.8 MHz subcarrier, the earth stations could be configured as shown in Table 1, section c. In comparing this system with the lower deviation signal it must be decided whether the increase in SNR overcomes the additional cost for 18 130 K LNA's and one 80 K LNA.

| Number of Earth Stations | Ant. Dia. (meters) | LNA Noise Temp (K) | CNR Margin Above JND (dB) | CNR (dB) | SNR (dB) |
|---|---|---|---|---|---|
| (a) ΔF = ± 7 MHz, B = 17.5 MHz | | | | | |
| 1 | 4.5 | 130 | 1.9 | 13.4 | 44.8 |
| 159 | 4.5 | 190 | 1.8-3.8 | 13.3-15.3 | 44.7-46.7 |
| (b) ΔF = ± 8 MHz, B = 20 MHz | | | | | |
| 1 | 4.5 | 130 | 1.3 | 12.8 | 45.9 |
| 159 | 4.5 | 190 | 1.2-3.2 | 12.7-14.7 | 45.8-47.8 |
| (c) ΔF = ± 10 MHz, B = 25 MHz | | | | | |
| 1 | 4.5 | 80 | 1.5 | 13.3 | 49.4 |
| 19 | 4.5 | 130 | 1.3-2.4 | 13.1-14.2 | 49.2-50.3 |
| 140 | 4.5 | 190 | 1.2-2.0 | 13.0-13.8 | 49.1-49.9 |

Table 1. Bush Earth Station Configuration for RCA Spacecraft F2, Alaskan Beam

Another alternative to be considered is the extra cost to receive a high deviation "standard" signal that is being transmitted on the Alaskan beam of F2 to Alaska and the states in the Pacific time zone. Assume that the television signal is transmitted with a peak deviation of 11 MHz and audio on a 6.8 MHz subcarrier and received with a 30 MHz IF filter. The earth station configuration for this situation is listed in Table 2. The use of the high deviation system yields high quality video and sound and a high SNR but requires upgrading of most of the LNA's from the configuration of Table 1b. The additional cost of this 11 MHz deviation configuration over that of the 8 MHz deviation was calculated to be $490,000 (1975 dollars)[4] for the 160 earth stations.

1. Whether a picture is unsatisfactory or not depends on the interest in the program material and the particular viewer involved. An unsatisfactory picture was defined and documented at RCA Laboratories with pictures of impulse noise on an IRE filtered unmodulated linearity pattern. Suffice it to say that the unsatisfactory picture is highly distorted although the images are perceivable.
2. No audio subcarrier was used in obtaining the curves of Figs. 1 and 2. It should also be noted that the 30 MHz filter had a noise bandwidth of 34 MHz whereas the noise bandwidths for the other filters did not differ significantly from the stated bandwidths.

It is likely that most high deviation, broadcast quality television for general distribution would be transmitted on the beam that covers both Alaska and the 48 contiguous states (the CONUS beam). It would be advantageous for the Bush communities to be able to receive these transmissions. Table 3 shows the earth station configurations that would be needed to receive such television transmissions. The extra cost of this design over the 8 MHz peak deviation was $5,702,500 (1975 dollars)[4].

Using the above information and considering the scheduling and monetary requirements, the State decided to procure 4.5m antenna, 190 K earth stations for the Bush service.

| Number of Earth Stations | Ant. Dia. (meters) | LNA Noise Temp (K) | CNR Margin Above JND (dB) | CNR (dB) | SNR (dB) |
|---|---|---|---|---|---|
| 1 | 4.5 | 45 | 2.2 | 13.2 | 51.5 |
| 4 | 4.5 | 80 | 2.0-2.6 | 13.0-13.6 | 51.3-51.9 |
| 128 | 4.5 | 130 | 1.2-2.5 | 12.2-13.5 | 50.5-51.8 |
| 27 | 4.5 | 190 | 1.2-1.4 | 12.2-12.4 | 50.5-50.7 |

Table 2. Earth Station Configuration for $\Delta F = \pm 11$ MHz, B = 30 MHz, Spacecraft F2, Alaskan Beam

### Comparison of Earth Station Television Receivers

We next investigated the possibility that there existed an earth station television receiver that would allow a better service for the Bush. Receivers made by nine manufacturers were tested at RCA Laboratories in a back-to-back configuration at 70 MHz, at RCA Alascom in a back-to-back configuration at 4 GHz, and over the satellite to a 4.5m, 190K earth station in Anchorage. Consider first the 70 MHz tests.

The most important parameter for comparing receivers for use with small earth stations is the minimum carrier-to-noise density (C/kT) at which the earth station can be operated. Computer projections of the minimum C/kT that will be received using the Alaskan beam of RCA SATCOM F2 is 85.8 dB Hz at all currently conceived Alaskan Bush locations except Atka when using earth stations with 4.5 meter antennas and 190K LNA's[4]. It was found from the experiments that a Bush Television System that uses deviations greater than 8 MHz is likely to yield pictures with impulse noise at some locations when the pictures contain highly saturated colors. In addition some margin must be provided for the eventual degradation that will likely occur.

Suppose the receivers are compared for C/kT performance at $\Delta F = 8$ MHz. Curves of minimum C/kT for just noticeable impulse distortion (JND) using no audio subcarrier and with the IF filter (if needed) that gave lowest JND for $\Delta F = 8$ MHz are shown in Fig. 3. It is seen that five of the receivers are able to operate at a peak deviation of 8 MHz and a C/kT of 85.8 dB Hz or lower without yielding any impulse noise. However, four of the tested receivers would yield impulse noise on the EIA color bar test pattern. The best receiver tested could operate at a 2.5 dB lower C/kT than expected at the worst Bush location before seeing impulse noise on the color bars.

| Number of Earth Stations | Ant. Dia. (meters) | LNA Noise Temp (K) | CNR Margin Above JND (dB) | CNR (dB) | SNR (dB) |
|---|---|---|---|---|---|
| 1 | 10 | 45 | 1.9 | 13.7 | 50.6 |
| 1 | 8 | 45 | 2.3 | 14.1 | 51.0 |
| 4 | 8 | 80 | 1.7-2.5 | 13.5-14.3 | 50.4-51.2 |
| 18 | 8 | 130 | 1.4-2.4 | 13.2-14.2 | 50.1-51.1 |
| 81 | 8 | 190 | 1.2-2.3 | 13.0-14.1 | 49.9-51.0 |
| 45 | 4.5 | 45 | 1.2-2.5 | 13.0-14.3 | 49.9-51.2 |
| 10 | 4.5 | 80 | 1.9-2.4 | 13.7-14.2 | 50.6-51.1 |

Table 3. Earth Station Configuration for $\Delta F = \pm 11$ MHz, Conus F1 or F2, B = 25 MHz

It is important to find out how gracefully the receivers degrade as the C/kT is decreased. Unfortunately this is not an easy thing to determine without subjective side-by-side tests. It appears that most receivers have an "unsatisfactory" picture at C/kT's from 77 to 81 dB Hz with $\Delta F = 8$ MHz. One of the receivers (receiver P) did not lose sync until the C/kT was lowered to 73 dB Hz.

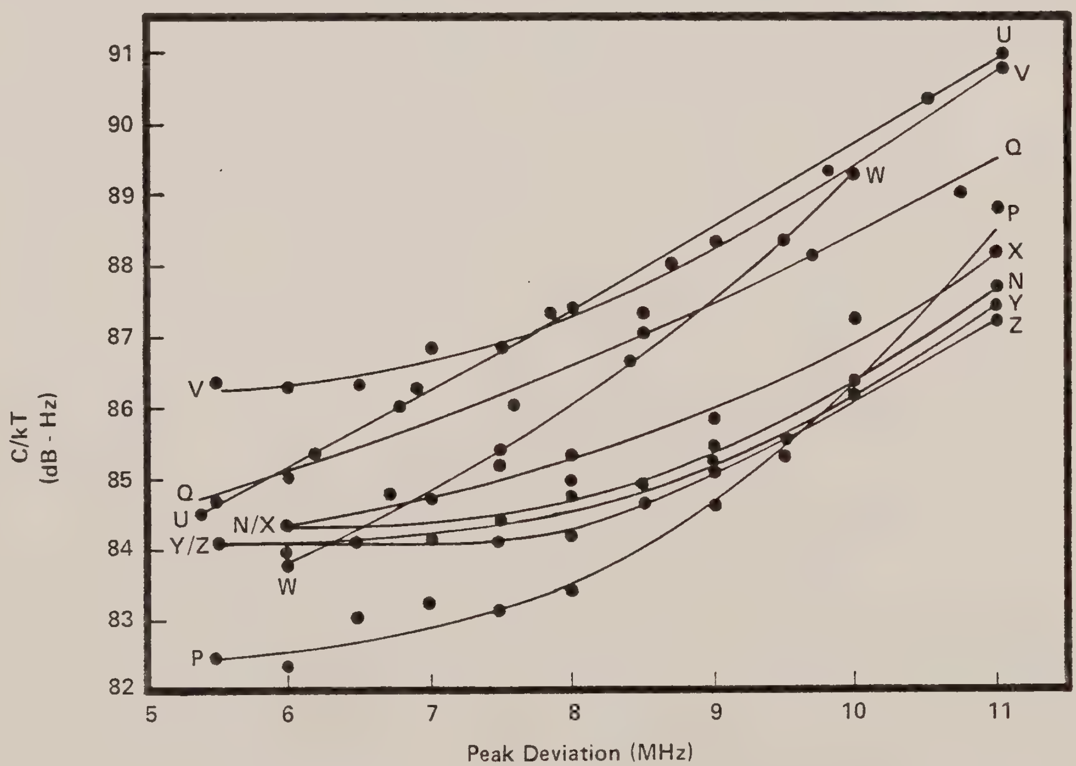



Figure 3. JND for Various Receivers

It is also important to compare the thermal noise in the picture for the different receivers operating above threshold. All receivers gave SNR reasonably close to theoretical. Hence, we believe the thermal noise in the picture is not a distinguishing factor between receivers.

Video distortion is another factor in the comparison of receivers. All receivers were able to achieve the previously specified minimum video distortions in the 70 MHz test and most receivers exceeded these specifications by a significant amount. Receiver Q yielded the least video distortion, followed by in order by receivers V, X, and Z. However, the video distortion at 8 MHz from any of the receivers is not in itself large enough to be perceptible.

From the 70 MHz tests it appeared that a number of television receivers would yield good quality television for the Alaskan Bush under the systems specifications of 8 MHz peak deviation, audio in a separate transponder, 4.5 meter antennas, and 190 K LNA's at all locations except one.

## Testing of the Bush Service in Alaska

The feasibility of the above communication system for delivering television to the Alaskan Bush was tested April 26 through May 12, 1976 using a small Bush Terminal located at the RCA Alascom plant in Anchorage, Alaska. Nine manufacturers supplied earth station television receivers for the tests. Evaluations of the receivers were made in both over-the-satellite and back-to-back RF tests. Representatives from the receiver manufacturers were present during the course of the tests for their particular receiver and made all the connections and adjustments necessary to optimize the performance of their receivers.

The originating video was modulated with a peak deviation of 8 MHz. Standard CCIR pre-emphasis was used. The peak-to-peak energy dispersal was 1.2 MHz. No audio subcarrier was included. Observatons of the EIA color bar test pattern and a 40 IRE linearity (staircase) pattern were made on both a picture monitor and a standard television set. Photographs were made of impulse noise on the waveforms as the carrier power in the up and down links was lowered to simulate possible degraded conditions in remote locations. Then the transponder was saturated and observations were made of perceived picture quality on standard program material. The material was generated from tape at an Anchorage television station, transmitted by microwave to the Bartlett earth station, and transmitted by satellite to a small earth station (4.5 meter antenna, 190K LNA) in Anchorage. Transponder number 11 of RCA Satcom F1 (then at 119°W) was used for the transmission. The program meterial consisted of excerpts from The Electric Company, which contained highly saturated colors, and super-imposed lettering that was electronically generated.

The receivers were then tested in a back-to-back configuration at C-band frequencies. Thermal noise was added to the signal to simulate the link characteristics. The carrier-to-noise density (C/kT) at which the video impulses were just noticeable (JND) and the signal-to-noise ratio (SNR) at various C/kT were recorded for each receiver. The injected noise was then removed and a number of video distortion characteristics were measured.

The most critical characteristic of receiver performance is the onset of impulse noise in a highly saturated color picture at a low carrier-to-noise density (C/kT). The C/kT at which the impulses were just noticeable (JND) in the EIA color bars are listed in Table 4. The receivers are listed in ascending order of C/kT at JND found in the RF tests. Also listed are the C/kT at JND results of the previous IF tests.

In practice the annoyance of a given population of impulses varies with different receiver implementations. In the region around JND the phase locked loop (PLL) receivers lose lock for a full cycle or more and seem to produce broader impulses than do discriminators. Another factor is the tendency of PLL detectors to concentrate impulses in areas of high chrominance and on picture transitions rather than distribute them randomly in the picture as does the conventional discriminator. This can be a highly annoying factor depending on the picture content. On the other hand, the C/kT difference from the JND point to the "unsatisfactory" point was, in general, larger for the PLL receivers than for the receivers with discriminators. This means that a larger degradation in C/kT could be tolerated before the picture becomes "unsatisfactory", a point in favor of the PLL detectors. The value of these factors (broad spikes not randomly distributed versus a useable picture at lower C/kT for PLL receivers) is difficult to assess. The Alaskan Bush system will be receiving a larger C/kT than required for JND point and not to the unsatisfactory point. Therefore, it seems that the broad spikes may be the more important consideration. However, these factors can be considered of more or less equal importance and the receivers can be judged on the magnitude of C/kT at JND. Receivers U, Q, and W are PLL receivers.

Receiver P with threshold extension is clearly superior with regard to JND performance. Receiver P exhibits the non-random impulse distribution but this does not detract from the approximate 1 dB of threshold extension over receiver Z. Receiver P also operated at the lowest C/kT before yielding an unsatisfactory picture. Receiver Z is clearly the next best with respect to JND performance. The remaining receivers can be grouped into two categories. Receivers U, X, and Y are able to operate at C/kT less then 87 dB Hz without visible impulse noise in the color bar picture. Receivers V, Q, W, and $\propto$ require a C/kT in excess of 87 dB Hz in order to avoid impulses in the picture. In both categories, one can differentiate between the performance of the best and worst receivers. However, the adjacent receivers can probably not be distinguished because they are within the experimental error of the testing method. In any case, the variations in performance in different units from the manufacturing process would more than likely exceed differences seen in the adjacent receivers in each category.

The measured signal-to-noise ratio for each of the receivers at a carrier-to-noise ratio for each of the receivers at a carrier-to-noise density of 86.5 dB Hz ranged from 45.5 dB to 48 dB. From a theoretical basis, the expected CCIR weighted SNR for this C/kT and a peak deviation of 8 MHz is 46.6 dB. The 2.5 dB difference in measured SNR is not judged to be significant.

All of the receivers (except for receiver $\propto$) met the minimum performance video distortion parameters specified earlier. Receiver $\propto$ exceeds the L-C delay delay specification by only 2 ns (50 ns specification). This could probably be corrected with a minor adjustment. Most receivers yielded very low video distortion parameters, e.g. differential gain $\approx$ 3%, differential phase $\approx$ 1°.

It is seen that the relative groupings of the receivers is the same in both IF and RF tests except for receiver U, which was improved for the RF tests. The manufacturer's representative for receiver W pointed out that the particular receiver that was used in Anchorage tested about 1.5 dB poorer than the previous receiver had tested at his location. It is seen that there is a consistent discrepancy between the JND at IF and RF for the top five receivers (except for U) of about 1.3 dB. One would expect the results obtained at RF to be worse than those at IF due to the lack of an absolutely flat amplitude response in the IF-RF-IF link. However, one would expect

this difference to be the order of a few tenths of a dB, not 1.3 dB. Unfortunately the receivers were not retested again at IF to check these assumptions. Other possible differences could be due to the slight nonflatness of the noise spectrum in each case. Note that the results for receivers Q and V did not vary that much.

These tests were conducted on spacecraft F1 to the small earth station in Anchorage. Actual TV service is via spacecraft F2 to many different remote locations. The implications of using some of the tested earth station receivers for transmission to the Bush will be discussed now.

| Receiver | IF Tests | RF Tests |
|---|---|---|
| P(TE) | 83.5 | 84.8 dB·Hz |
| ----- | ------ | -------- |
| Z | 84.2 | 85.6 |
| ----- | ------ | -------- |
| U | 87.3 | 86.1 |
| X | 84.7-85.3 | 86.3 |
| Y | 85.3 | 86.6 |
| ----- | ------ | -------- |
| V | 87.9 | 87.5 |
| Q | 87.1 | 87.9 |
| W | 86.0 | 88.2 |
| α | - | 88.3 |

Table 4. Comparison of C/kT at JND

Suppose that receiver P is to be used at all Bush locations. The C/kT at JND found in the RF tests was 84.8 dB Hz. The computer generated C/kT to 160 Bush locations is found in reference 4. Let us suppose that a 4.5m antenna is to be used at all locations and a 190K LNA is to be used at all locations except Atka, which will use a 130K LNA. Then the 160 Bush earth stations can be served with a 1 to 3 dB CNR margin above JND and a CCIR weighted SNR between 45.8 dB and 47.8 dB.

It is possible that a few of the other receivers can be used at some Bush locations. Suppose that a margin of 1 dB is required at all locations. Then receiver Z could be used at 154 locations, but the margin would be 0.8 dB less than that for receiver P. Eighty-six of these locations would have margins greater than 2 dB when using receiver Z. One would have to be careful about the use of the other receivers in the next grouping of Table 4. For example, if receiver Y is used, fewer than 86 earth stations would have margins greater than 1 dB. None of the receivers in the lower grouping should be used.

It is, therefore, concluded that high quality television can be delivered to the Alaskan Bush with the F2 spacecraft, 4.5m earth station antennas, 190K LNA's at all locations except Atka. The CCIR weighted SNR will be between 45.8 dB and 47.8 dB, the margin above JND will be between 1 and 3 dB at all locations giving an availability of no impulses of color bars of almost .99 at 3 locations and much better than .99 at the others. Under normal circumstances, it is unlikely that the Bush will receive an unsatisfactory picture.

## Two Television Channels Per Transponder

The parameters for transmitting two color television channels per transponder to the large earth stations in Alaska were analyzed[6]. In addition, a number of experiments were made over the satellite to determine the optimum parameters to use with the RCA satellites. The television signals were received at various times by earth stations with antenna diameters of 10 meters, 13 meters, and 30 meters. The following parameters were varied:

Power backoff; saturation to −15 dB
Peak Video Deviation; 5 MHz to 8 MHz
IF Bandwidth; 15 MHz, 16 MHz, and 17.5 MHz
Carrier position; ±8 MHz to ±10 MHz from channel center
Location of Audio Subcarrier; 5.8 MHz, 6.2 MHz, 6.8 MHz
Peak Deviation of the Main Carrier by the Audio Subcarrier; 1 MHz - 2 MHz

Data was taken over the satellite and in various back-to-back modes. Data on CNR, SNR, video impulse noise, video crosstalk, short-time waveform distortion, luminance-chrominance delay, differential gain, differential phase, audio into video, audio clicks, audio SNR and audio total harmonic distortion were taken for many of the variations.

At a transmitted power near the saturation of the satellite transponder, considerable color crosstalk occurred when there was a highly saturated color on one of the two channels. This crosstalk is caused by the nonlinearities of the satellite transponder and the phase response of the satellite input mix filter. The existence of two carriers means that there is both amplitude and phase modulation in the transponder. The presence of group delay inequalities cause phase errors in the demodulated isgnal. The amplitude modulation is converted into phase modulation (AM/PM conversion) by the TWT in the satellite. Both phenomena result in crosstalk from one television signal into the other. The crosstalk can be reduced by group delay equalization on the transmit side. The inclusion of group delay equalization reduced the video crosstalk in actual transmission by almost one half and improved the video distortion parameters significantly.

Further work was done to minimize the visible color crosstalk between the two television signals. This led to the development of a video processing technique which was named Alternate Line Delay (ALD)[7]. The use of this technique allows increased transmitted power and the resulting higher SNR and CNR margin above threshold. It also makes any visible color crosstalk imperceptible on television sets.

The parameters selected for the Alaskan two channel per transponder transmission were:

Total input backoff = 6 dB
Peak Video Deviation = 6.7 MHz
Peak-Peak Energy Dispersal = 0.5 MHz
Carrier Separation = 19 MHz
IF Bandwidth = 17.5 MHz
Transmit Group Delay Equalization in both channels
ALD in one channel

The video parameters measured at the RCA Americom Earth Station (G/T = 32.7 dB/K) outside Los Angeles, CA were:

SNR = 48.5 dB
CNR = 18.3 dB
Differential Gain = 6%
Differential Phase = 2°
Average Crosstalk[7] = 3.6% (not visible in the picture due to the ALD)

The power transmitted could be reduced 7 dB before impulse noise appeared in the picture. This means that the CNR margin is at least 7 dB. For example, if 5 dB is lost in the uplink another 2.9 dB can be lost in the downlink before impulses appear in the EIA color bars (JND).

The theoretical signal-to-noise that could be received by other earth stations is shown below for an EIRP = 34 dBw and an antenna look angle of about 30°:

| Antenna Diameters (m) | LNA Noise (K) | SNR (dB) |
|---|---|---|
| 30 | 55 | 51.7 |
| 13 | 55 | 48.8 |
| 10 | 55 | 47.2 |
| 10 | 190 | 44.7 |

It is seen that the two channel per transponder service is not "broadcast quality" (56 dB). However, a picture that has an SNR=48 dB, for example, is better than any point on the TASO scale. One can make a linear projection of the TASO data that indicates that 80% of the people would rate the picture as excellent[3]. Cavenaugh and Lessman[8] indicate that about 2 of 10 expert viewers would rate the noise as just perceptible or better, i.e., most expert viewers can readily see the noise. So the 48 dB picture has noise that can be seen at close range by experts, but the noise is so insignificant that the picture is judged as excellent by most people.

It should be noted that the SNR can be increased by about one half dB by reducing the backoff. However, the crosstalk increases by about 4 dB. Even though the interference is not visible in the picture because of the use of an ALD, it is very annoying on the waveform monitor and vectorscope. It should also be noted that the SNR can be increased by noise reduction techniques. It appears that 3 dB of noise reduction can be accomplished by video line-to-line techniques and 6 dB or more can be obtained by frame-to-frame techniques with essentially no resulting artifacts.

It is therefore concluded that the two channel per transponder service offers promise for many television applications.

## Conclusions

Domestic satellite television service began on a regular basis to the State of Alaska on Jan. 15, 1977. The service consists of 2 channels per transponder to large communities and one channel per transponder to rural communities. The CCIR weighted signal-to-noise ratio for the 2 channel television service to the Anchorage earth station should be about 52 dB and to the Juneau earth station about 49 dB. The received signal-to-noise in the rural communities should range from about 46 dB to 48 dB depending on the location.

## Acknowledgements

The author would like to thank the many people of the State of Alaska, RCA Alascom, RCA Americom, and RCA Laboratories who participated in this program. Particular gratitude is expressed to L. Abbott, R.P. Borchardt, R.P. Dowling, G. Elliot, D. Fremont, D. Greenspan, W.T. Rowse, and R. Wilson.

References

1. G.W. Beakley, and L. Abbott, "Deviation-Bandwidth Tradeoffs for Television Transmission" to be published in the RCA Review.
2. G.W. Beakley, "Television to Small Earth Stations," IEEE Trans. on Broadcasting, Vol. BC-22, No. 3, Sept. 1976.
3. G.W. Beakley and P.M. Nadkarni, "Evaluation of Scheme for Television Transmission to Small Earth Stations", RCA Internal Report.
4. G.W. Beakley, "Television to the Alaskan Bush," RCA Internal Report.
5. R.A. Ulene, "Subjective Effects of Bit Errors in a PCM Color Television System", RCA Review, Vol. 37, No. 3, Sept. 1976.
6. G.W. Beakley, "Two Television Channels Per Transponder in Satellite Communications," RCA Internal Report.
7. L. Abbott and G.W. Beakley, "Reduction of Visible Color Crosstalk by Alternate Line Delay," to be published.
8. J.R. Cavenaugh and A.M. Lessman, "The Subjective Effect of Random Noise Spectra on 525 Line NTSC Color Television", J. SMPTE, Vol. 83, No. 11, Oct. 1974.

# TELEVISION TO SMALL EARTH STATIONS

G.W. Beakley
Manager - Engineering
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Abstract** *Television transmission to small inexpensive earth stations is now being explored using conventional domestic satellites. A number of alternatives exist for the technical formatting of the television signal. Some of the tradeoffs in video deviation, bandwidth, and location of the television sound for frequency modulated television are discussed in this paper. The paper is concluded with an example of a system design for the Alaskan Bush communities.*

## TELEVISION TO SMALL EARTH STATIONS*

### Introduction

The transmission of good quality television by satellite to expensive earth stations with large antennas is very common. The transmission to inexpensive earth stations with small antennas has been accomplished using high power satellites. This paper will consider television transmission to small earth stations by conventional lower power domestic satellites. Considerable cost savings can be made in the ground segment or in the space segment using these procedures.

Low satellite power and low earth station gain-to-system noise temperature (G/T) result in FM demodulators operating in the vicinity of the FM threshold. This forces a choice between bandwidth large enough to allow the deviation needed for a good signal-to-noise ratio (SNR) but small enough so that the noise does not cause operation below the FM threshold. By judicious choice of the video and audio deviation, bandwidth, and preemphasis one can obtain a very satisfactory transmission scheme. This paper discusses tradeoffs between some of the transmission parameters and the quality and reliability of the television transmission service. It further illustrates the design procedure with an example of a system design for television transmission to 160 communities of the Alaskan Bush.

### Bandwidth

A generally accepted rule for determining the bandwidth that is needed by a frequency modulated signal is called Carson's rule. Carson's rule states that the significant bandwidth occupied by the spectrum of a frequency modulated sinusoid is twice the sum of the maximum frequency deviation and the fundamental modulation frequency. If the occupied bandwidth is 36 MHz and the maximum baseband frequency is 6.8 MHz, the general practice of applying Carson's rule would yield a maximum frequency deviation of 11.2 MHz. However, the television signal is not a sinusoid and one can "overdeviate" to reflect the statistical loading of the video signal. The amount of overdeviation that can be permitted for use with the NTSC television signal is the subject of the next section.

### Picture Quality

The specification of television picture quality is a complex problem that is under constant evolution. RCA Laboratories currently measures 21 video parameters to ascertain the performance of a television transmission system.

Various groups have defined television transmission parameter values for quality television (1) - (7). Since many of the values differ from document to document, we take the most stringent parameter values for satellite transmission from these references and call a signal with those values a broadcast-quality signal. These values are found in Table 1. Note that a satellite link which yields this high quality television must certainly be considered broadcast quality. Signals that do not meet some of these parameter specifications may also be considered broadcast quality in some of the references.

In some cases of television to small earth stations, there is little source of transmission degradation other than the satellite link. It therefore seems reasonable to allow this link to yield video quality lower than broadcast

*Reprinted from the IEEE Transactions on Broadcasting, Sept. 1976

quality, but not so low as to be objectionable. It was decided that the parameter values found in Table 2 would yield a television picture without perceptible distortion to most (if not all) viewers. A television signal with this amount of distortion is called in this report "home quality." These four parameters were isolated because they are the first video distortion parameters to be so affected by overdeviation as to become objectionable. One need not be overly concerned about the definition of home quality because overdeviation that produces home quality picture requires a high carrier-to-noise ratio (CNR) than desirable for most small earth station applications.

Table 1

| Transmission Parameter | Satellite Link Value For Broadcast Quality |
|---|---|
| **Linear Distortion** | |
| Field Time Waveform Distortion | 1% |
| Line Time Waveform Distortion | 1% |
| Short Time Waveform Distortion, SD | 4% |
| Luminance-Chrominance Gain | 6% |
| Luminance-Chrominance Delay | 26 ns |
| **Nonlinear Distortion** | |
| Differential Gain | 4% |
| Differential Phase | 1.5° |
| Chrominance-Luminance Intermod | 2% |
| Chrominance Nonlinear Gain | 2% |
| Chrominance Nonlinear Phase | 2° |
| Luminance Nonlinearity | 6% |
| Sync Nonlinearity | 5% |
| Differential Burst Gain | 2% |
| Differential Burst Phase | 1° |
| **Noise (Relative to Signal)** | |
| CCIR Weighted Random | -56 dB |
| Peak-to-peak (P-P) Impulse | -25 dB |
| P-P Periodic Low Frequency | -50 dB |
| P-P Periodic High Frequency | -64 dB |
| P-P Crosstalk | -60 dB |

Table 2

| Transmission Parameter | Satellite Link Value For Home Quality |
|---|---|
| Short Time Waveform Distortion, SD | 10% |
| Luminance-Chrominance Delay | 50 ns |
| Differential Gain | 10% |
| Differential Phase | 5° |

**Overdeviation** Experiments were conducted to determine the effect of overdeviation and low CNR on the resultant picture quality. A Scientific-Atlanta Model 461WB Exciter (modulator) and 411WB Receiver were connected at IF. The capability of adding random noise for simulating any CNR was also included. Standard Intelsat IV delay equalized IF filters with nominal bandwidths of 30, 25, 20, and 17.5 MHz were tested in the receiver. CCIR preemphasis and deemphasis circuits were used. No attempt was made to simulate the nonlinearities of the transponder. The only nonlinear effects considered were those resulting from the overdeviation. The satellite is expected to yield contributions to differential gain, differential phase, chrominance-luminance intermod, and chrominance nonlinear phase. Those circumstances where the satellite is expected to yield a significant effect are pointed out in the following discussions. Also, these experiments concern transmission of video alone. The inclusion of sound on a subcarrier or on a separate carrier in the video transponder will be considered later.

Figures 1 and 2 illustrate two types of curves that can be constructed to aid in the design of a television transmission system. Figure 1 was drawn for a 25 MHz filter with noise bandwidth of 25.3 MHz. Two vertical lines that are labeled broadcast and home are shown at peak deviations 10.5 and 12.0 MHz, respectively. These are the maximum deviations that can be used with the 25 MHz filter and still meet the broadcast and home quality video distortion standards as previously described. The resulting parameter values are listed in Table 3. APL is the alternate average picture level in percent of total luminance. APL = NORM is the normal APL for the signal used to test the given parameter. The short time waveform distortion SD was measured according to IEEE Standard 511-1974.

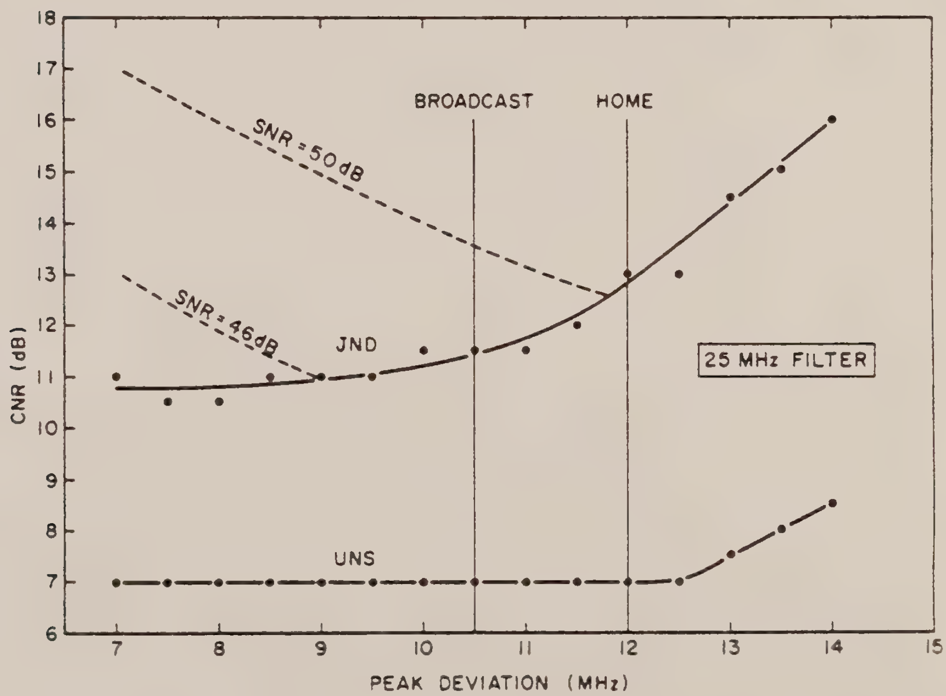



Figure 1

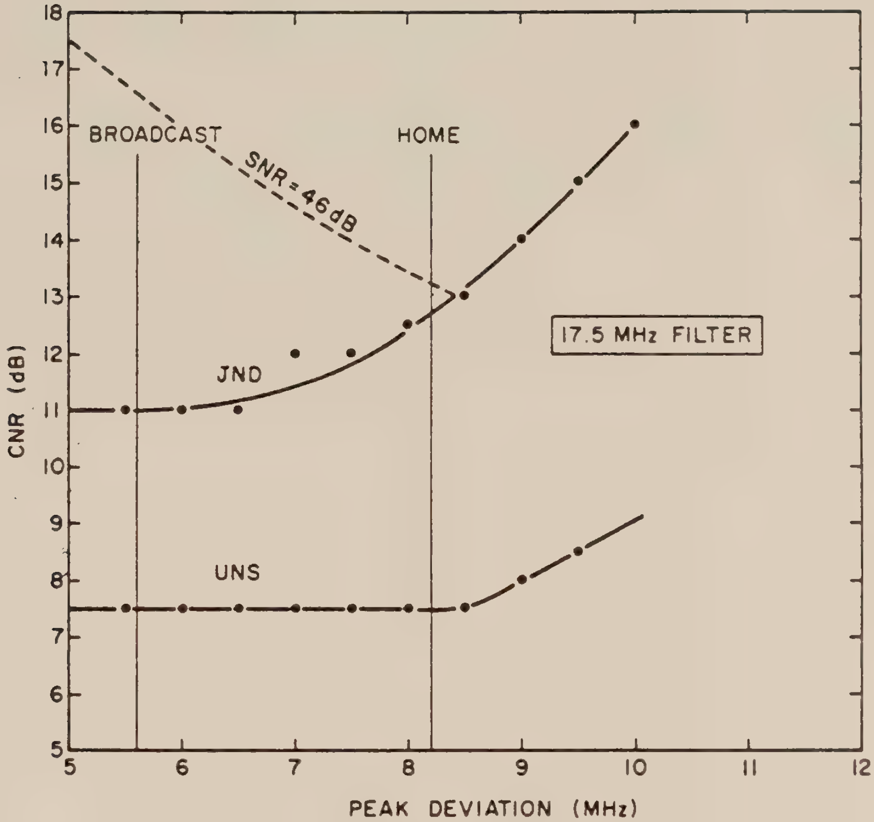



Figure 2

The satellite may yield a 3 percent differential gain contribution. If this is combined using a 3/2 power law with the earth station contribution at the 10.5 MHz deviation, the resultant differential gain is 4.76 percent at 10 APL, 4 percent at the normal APL for the five step linearity pattern, and 4 percent at 90 percent APL. Hence for a 3 percent differential gain in the satellite, the broadcast quality differential gain specification is slightly exceeded at the peak deviation of 10.5 MHz and an APL of 10 percent.

The upper horizontal curve in Fig. 1 locates the CNR at which the impulse noise due to threshold effects or truncation is just noticeable, i.e., just noticeable distortion (JND). The lower horizontal curve marks the CNR at which the picture becomes unsatisfactory.[1]

The horizontal curves were obtained from the judgment of an experienced viewer who observed split-field 75 percent color bars on a Tektronix picture monitor and on an RCA color TV receiver as the CNR was lowered. In general, the onset of impulse noise was noticed on the monitor at least as soon as on the RCA receiver so that the data on the monitor were used for the curves. However, at the unsatisfactory level, the picture quality seemed better on the monitor than on the receiver. Both the receiver and the monitor held vertical and horizontal sync at the unsatisfactory level. The monitor lost sync with 2 - 3 dB lower CNR (CNR $\simeq$ 5 dB) and the receiver lost sync at a still lower CNR.

These curves can be used in assessing the quality of a TV transmission system. For example, with the Scientific-Atlanta Modulator and Demodulator and the 25 MHz filter, video distortion less than that specified for broadcast

quality can be achieved for deviations up to ±10.5 MHz. Notice the Carson's bandwidth is exceeded. A further increase in deviation to ±12 MHz will yield home quality transmission. An increase in deviation beyond this point will result in perceived distortion for some people. If the CNR is low, the effects are worse with large deviations because the carrier is truncated by the edges of the filter and goes below the noise, thereby yielding truncation impulse noise. If the CNR is above the JND for the particular deviation, no impulse noise is seen in the picture. It should also be recognized that a low deviation results in a low SNR. If the CCIR weighted SNR objective is greater than 46 dB, one should operate in the region above the dashed line labeled 46 dB. Therefore, if the link objectives are SNR ⩾46 dB and home quality video distortion, the system should be operated in the region bounded by the SNR = 46 dB, the JND, and the home lines.

Table 3
25-MHz Filter

| Transmission Parameter | 25 MHz Filter | | | | | |
|---|---|---|---|---|---|---|
| | Broadcast Quality ±10.5 MHz | | | Home Quality ±12 MHz | | |
| | APL=Norm | APL=10 | APL=90 | APL=Norm | APL=10 | APL=90 |
| SD (%) | 1% | 4% | 1% | 5% | 10% | 2% |
| L-C delay (ns) | 12 ns | 16 ns | 20 ns | 20 ns | 16 ns | 24 ns |
| Diff. Gain (%) | 2% | 3% | 2% | 2.5% | 4% | 2.5% |
| Diff. Phase (°) | 0.9° | 1.3° | 1.3° | 1.2° | 1.8° | 1.8° |

Table 4
17.5-MHz Filter

| Transmission Parameter | 17.5 MHz Filter | | | | | |
|---|---|---|---|---|---|---|
| | Broadcast Quality ±5.6 MHz | | | Home Quality ±8.2 MHz | | |
| | APL=Norm | APL=10 | APL=90 | APL=Norm | APL=10 | APL=90 |
| SD | .8% | .8% | .8% | 2% | 3.5% | 1% |
| L-C Delay | 12 ns | 26 ns | 12 ns | 30 ns | 50 ns | 44 ns |
| Diff. Gain | 1.5% | 1% | 2% | 2% | 2.5% | 4% |
| Diff. Phase | 1.5° | 1.5° | .8° | 1.8° | 2° | .8° |

Curves for a 17.5 MHz filter are shown in Fig. 2. The four video distortion parameters corresponding to the broadcast and home quality lines of that figure are listed in Table 4.

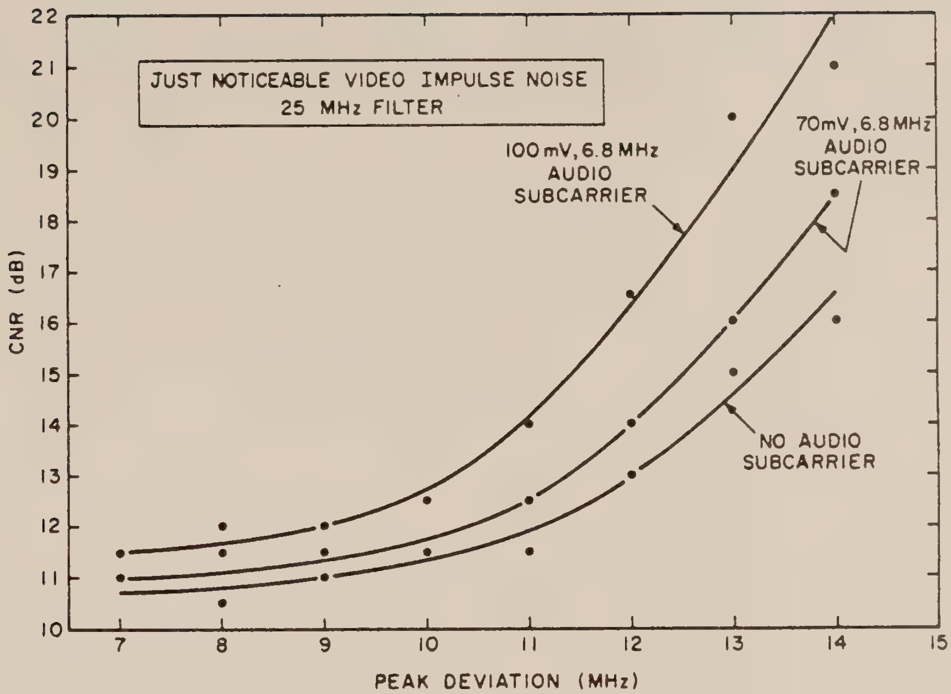



Figure 3

If audio is included on a 6.8 MHz subcarrier, just noticeable video impulse noise occurs at a higher CNR. Fig. 3 shows the effects of different levels of the 6.8 MHz subcarrier at a peak deviation of 100 kHz on the JND curve for the 25 MHz filter. For this filter and a 6.8 MHz subcarrier the 70 mV subcarrier seems to be about optimal for the small earth station application since the onset of just noticeable audio clicks occurs at about the same CNR as does the video impulse noise for video deviations greater than ±8.5 MHz. It is seen that for a video deviation of ±10.5 MHz in a 25 MHz filter, the inclusion of a 70 mV 100 kHz subcarrier requires about 0.5 dB higher CNR in order to avoid the onset of impulse noise than if no subcarrier is included.

It is interesting to note how some of the video parameters vary with deviation. Table 5 shows this variation when a 25 MHz filter is used on the transmit side and 17.5 MHz filter on the receive side. The short time waveform distortion SD seems to be most affected by overdeviation. This agrees with this viewer's perception of a highly overdeviated signal. At a high CNR one first perceives a certain amount of fuzziness, and later, a tearing on black-to-white transitions as overdeviation becomes severe. When the deviation is increased further, changes in hue and saturation from the original picture are noticed.

Curves of measured CCIR weighted SNR versus CNR are shown in Fig. 4. These curves show good agreement with the following equation for CNR above 12 dB:

$$SNR = CNR + 10 \log_{10} (\Delta F^2_{MHz} \quad B_{MHz}) + 2 \text{ dB}$$

where $\Delta F_{MHz}$ is the peak deviation in megahertz and $B_{MHz}$ is the predetection noise bandwidth in megahertz. This equation agrees with theory and has been found accurate in field tests with other manufacturers' hardware.

There are a number of alternatives for handling the television audio. It is reasonable to place one or more FM sound carriers above 88 MHz and pick

them off at IF. Cost = I effective FM receivers are available for less than \$300. A computer program that considers third order intermod and optimally spaces the carriers has yielded the following (see Table 6) alternatives with EIRP = dBw, G/T = 19.7 dB/K, 240 kHz audio bandwidth, and no input backoff. Certainly, one audio carrier seems feasible and more than one carrier may be considered in the overall design.

Other possibilities for audio services include an audio subcarrier and a separate program audio carrier in another transponder. The cost of the audio subcarrier demodulator runs about \$1500 whereas the cost of a separate program audio runs about \$4500.

Table 5

VIDEO PERFORMANCE VERSUS DEVIATION FOR A 17.5-MHZ RECEIVER FILTER

| | Peak Deviation (MHz) | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 |
| Short Time Distortion - SD | .8% | .8% | .8% | 2% | 5% | 35% |
| Luminance-Chrominance Gain | -1% | -1% | -3% | -5% | -7% | -8% |
| Luminance-Chrominance Delay | 24 ns | 28 ns | 48 ns | 52 ns | 60 ns | 65 ns |
| Differential Gain | 1% | 2% | 2% | 2.5% | 3% | 4% |
| Differential Phase | 1.2° | 1.3° | 1.7° | 1.8° | 1.9° | 1.7° |
| Chrominance-Luminance Intermod | <.1% | <.1% | <.1% | <.1% | <.1% | <.1% |
| Chrominance Nonlinear Phase | .2° | .2° | .35° | .4° | .45° | .6° |

Table 6

| Number Of Audio Carriers | Decrease In Video CNR | Video Carrier to-Intermod | Audio Carrier to-Intermod |
|---|---|---|---|
| 1 | 0.5 dB | 23.4 dB | 27.0 dB |
| 2 | 1.0 dB | 20.2 dB | 23.8 dB |
| 3 | 1.5 dB | 18.3 dB | 21.6 dB |

## Satellite Link Calculations

The carrier-to-thermal noise density in the downlink is given by

$$(C/kT)_D = EIRP - (L_{FS} + L_o) + G/T - k$$

The EIRP is the effective isotropically radiated power in decibels referred to 1 W and is a maximum of about 37 dBw at beam center for conventional domestic satellites. $L_{FS}$ is the free space loss and at 4 GHz ranges from 196.0 196.0 to 196.7 dB depending on the location of the receiving earth station. $L_o$ is the additional operating loss and ranges from 0.14 dB for oxygen and water vapor losses at a 30° elevation angle to a few decibels for rain storm conditions. The G/T is the gain to system temperature figure of merit for the receiving earth station. For a 4.5m antenna and 190K LNA the G/T ranges from 19.4 dB/K to 20.0 dB/K, varying mainly with the antenna elevation angle. The parameter k is Boltzmann's constant.

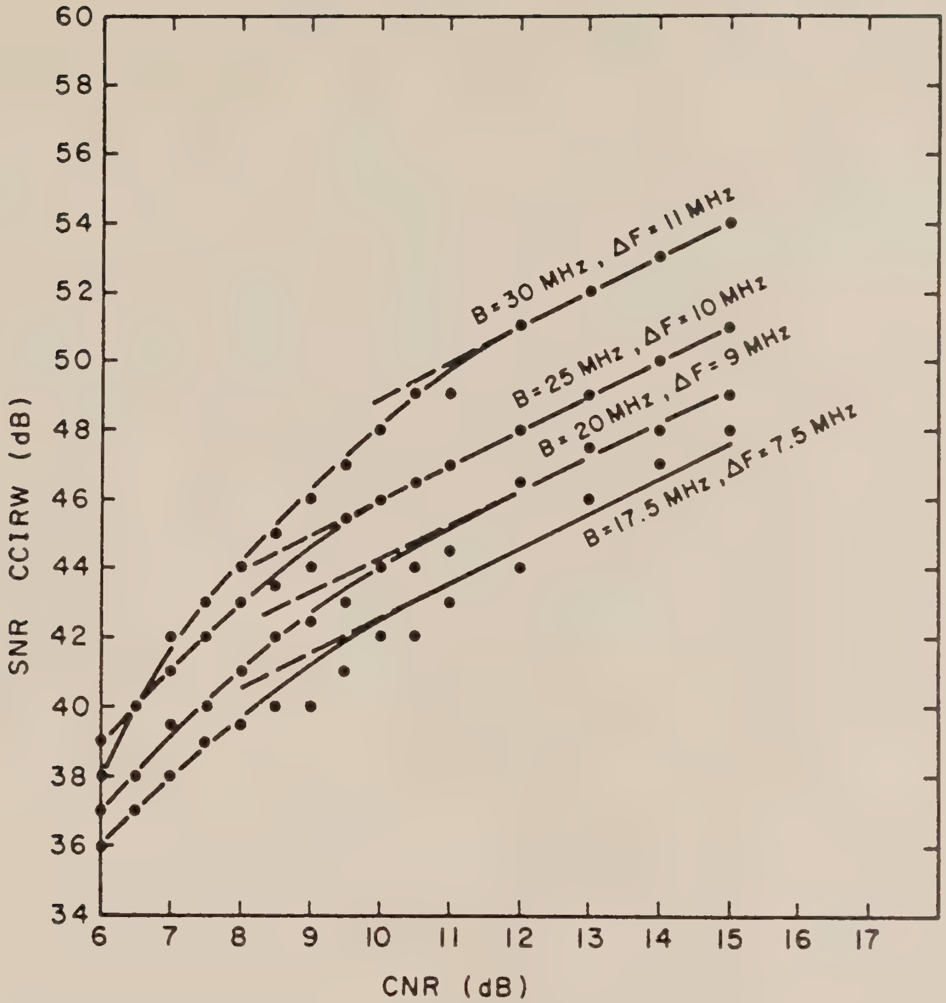



Figure 4

**Alaskan Bush Example**

For a "typical" Alaskan location with good weather conditions, the free space loss might be 196.6 dB, $L_o$ = 0.4 dB, EIRP = 36 dBw, and G/T = 19.7 dB/K, resulting in received $(C/kT)_D$ of 87.3 dB/Hz. The carrier-to-thermal noise density on the uplink from a larger earth station is about 104 dB/Hz. The received C/kT is therefore about 87.2 dB/Hz. Suppose a receiver noise bandwidth of 17.8 MHz is used in the small earth station. The CNR is then 14.7 dB. Cross polarization interference, copolarization interference, external interference, and adverse weather conditions will reduce the CNR further.

A computer program was written to allow a number of alternative television transmission designs to be considered for the Alaskan Bush application. The EIRP's to each village were generated assuming a satellite position of 119°W for RCA spacecraft F2. For transponder No. 15 (4 GHz down), a path loss of 197.0 dB (free space plus normal atmospheric loss) was assumed for all locations. In addition, 0.2 dB was subtracted to account for uplink thermal noise and interference. The G/T was computed using a gain of 43.4 dB for a 4.5m antenna and 48.4 dB for an 8m antenna. The system noise temperatures $T_S$ were computed using the elevation angles for each village by the formula:

$$T_S = T_R + T_A$$

where $T_R$ is the noise temperature of the LNA and $T_A$ ranges from 66K for a 5° elevation angle to 40K for a 30° elevation angle.

The computer program allows input of the desired noise bandwidths, CNR, margin, and number of decibels of threshold extension. The program then assigns the appropriate antenna and LNA to each village from two possible antenna sizes (4.5 or 8m) and four possible receiver noise temperatures (190, 130, 80, and 45K).

Table 7

BUSH EARTH STATION CONFIGURATION FOR
$\Delta F = \pm 7$ MHz, B = 17.5 MHz, RCA Spacecraft F2, Alaskan Beam, No TED

| Number of Earth Stations | Ant. Dia. (meters) | LNA Noise Temp (°K) | Margin Above JND (dB) | CNR (dB) | SNR (dB) |
|---|---|---|---|---|---|
| 1 | 4.5 | 130° | 1.9 | 13.4 | 44.8 |
| 159 | 4.5 | 190° | 1.8-3.8 | 13.3-15.3 | 44.7-46.7 |

Consider the transmission of the television signal with deviation ±7 MHz on spacecraft F2. If a Scientific-Atlanta Model 411WB Receiver or its equivalent is used, the 160 possible Bush earth stations can be configured as shown in Table 7. The margin above JND is the CNR margin above which the JND due to threshold or truncation impulse noise occurs. This means that a loss of 1.8 dB in CNR would cause the onset of just noticeable impulse noise at some of the Bush earth stations.

Other earth stations would have to lose up to 3.8 dB before the onset of impulse noise. The margin before receiving an "unsatisfactory" picture is 4 dB plus the margin above JND. Therefore, under normal circumstances it is unlikely that the picture will become "unsatisfactory."

Table 8

BUSH EARTH STATION CONFIGURATION FOR
$\Delta F = \pm 7.5$ MHz, B = 17.5 MHz, RCA Spacecraft F2, Alaskan Beam, No TED

| Number of Earth Stations | Ant. Dia. (meters) | LNA Noise Temp (°K) | Margin Above JND (dB) | CNR (dB) | SNR (dB) |
|---|---|---|---|---|---|
| 1 | 4.5 | 130° | 1.5 | 13.4 | 45.4 |
| 159 | 4.5 | 190° | 1.4-3.4 | 13.3-15.3 | 45.3-47.3 |

It can be argued that a deviation of ±7.5 MHz would be more desirable. The primary reason for this argument is that this deviation may become standard for half transponder service to large earth stations. Hence the transmitting and receiving equipment may become less expensive. The resulting configuration of Bush earth stations is shown in Table 8. Note that increasing the deviation to ±7.5 MHz essentially yields 0.6 dB better SNR at a cost of 0.4 dB less margin above JND. In (8, appendix 1) it is estimated that the CNR margin needed for an availability of 0.99 (an average of 1 h and 40 min of degraded signal per week) is 1.2 dB for a 190° LNA and 1.8 dB for a 45° LNA at an elevation angle of 10°. Based on this estimate it is concluded that the availability of a signal unimpaired by impulse noise is greater than 0.99 for this earth station configuration.

Another aspect that should be considered in selecting the optimum deviation for broadcast to Alaska is the inclusion of the television audio. It was previously concluded that the use of one audio channel on a separate carrier in the same transponder or the use of an audio subcarrier will raise the JND by approximately 0.5 dB. If audio is to be included in one of these fashions, it appears that the ±7 MHz deviation would be preferable in that the minimum margin above JND would be 1.3 dB. Audio included in a separate transponder would, however, seem to favor the ±7.5 MHz design because of the increased SNR and the adequate CNR margins.

Table 9

EARTH STATION CONFIGURATION FOR
$\Delta F = \pm 10$ MHz, B = 17.5 MHz, RCA Spacecraft F2, Alaskan Beam, No TED

| Number of Earth Stations | Ant. Dia. (meters) | LNA Noise Temp (°K) | Margin Above JND (dB) | CNR (dB) | SNR (dB) |
|---|---|---|---|---|---|
| 1 | 4.5 | 80° | 1.5 | 13.3 | 49.4 |
| 19 | 4.5 | 130° | 1.3-2.4 | 13.1-14.2 | 49.2-50.3 |
| 140 | 4.5 | 190° | 1.2-2.0 | 13.0-13.8 | 49.1-49.9 |

If it were desirable to increase the SNR to a minimum of, for example, 49 dB, the deviation could be increased to ±10 MHz. The sound could be included at 70 mV on a 6.8 MHz subcarrier, and the earth stations could be configured as shown in Table 9. In comparing this system with the lower deviation signal, it must be decided whether the increase in SNR overcomes the additional cost for 18 130K LNA's and one 80K LNA. Also, this wide deviation precludes the use of a separate audio carrier because of intermodulation in the transponder and hence requires the higher cost audio subcarrier unit.

**Conclusion** Television can be transmitted by conventional domestic satellites and received by small inexpensive earth stations. The earth stations can be configured with 4.5m antennas, 190K LNA's, downconverters, and demodulators for a current total cost in quantity of about $18,000 each plus shipping and installation, by restricting the bandwidth and overdeviating with respect to Carson's rule. The resultant picture distortion is minimal and the CCIR weighted SNR can be 45 dB or greater depending on the system design.

**Acknowledgment** The author wishes to thank RCA Globcom for furnishing the impetus for this program and L. Abbott, R. Borchardt, A. Guida, P. Nadkarni, and many others of RCA Laboratories for their helpful discussions, programming, and hardware testing.

References

(1) NTC Report No. 7, "Joint committee of television broadcasters and the Bell system" published by PBS, June 1975.
(2) Standards proposal to replace RS-250A, EIA-SB-1193 EIA draft.
(3) "Network requirements for a satellite television program distribution system," PBS E 7212, Dec. 15, 1972.
(4) "Network requirements for a satellite television program distribution system," N1406, Aug. 12, 1971.
(5) *Transmission Systems for Communications*, Bell Telephone Laboratories, Dec. 1971.
(6) CCIR Rec. 421-3, vol. XII, XIII Plenary Assembly, Geneva, 1974.
(7) Selected C.C.I.T.T. recommendations relating to international sound and television programme transmissions, The International Telecommunication Union 1974.
(8) G.W. Beakley and P.M. Nadkarni, "Evaluation of schemes for television transmission to small earth stations," RCA Internal Report.
(9) G.W. Beakley and R.E. Flory, "Television by satellite experiment conducted at Scientific-Atlanta," RCA Internal Report.

FOOTNOTES:

1. Whether a picture is unsatisfactory or not depends on the interest in the program material and the particular viewer involved. An unsatisfactory picture was defined and documented at RCA Laboratories with pictures of impulse noise on an IRE filtered unmodulated linearity pattern. Suffice it to say that the unsatisfactory picture is highly distorted although the images are perceivable.

# LINK ANALYSIS

Patrick H. Nettles, Ph. D.
Manager, SCPC Engineering
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## LINK ANALYSIS

### INTRODUCTION

In many of the papers presented in this conference, we are given descriptions of various equipment characteristics and physical effects. In this paper, we consider the ways that these factors combine to determine the quality of the received signal for a satellite transmission system. The analysis and discussion is primarily directed toward FM video transmission, although applications for FDM-FM links and PSK digital communications transmission are also considered briefly.

This discussion involves a two step process:

a. The RF link analysis, which is concerned with the received RF carrier-to-noise ratio in the IF bandwidth (prior to demodulation), and,
b. Determination of the effect of the satellite link noise (determined in the previous analysis) on the transmitted signal, which is expressed for video or message transmission as a baseband signal-to-noise, and for digital communications as a bit-error-rate for the data stream.

To develop the discussion of the RF link analysis, we begin with a brief review of the pertinent system parameters which affect the link noise for a satellite transmission system. The combination of these factors for the link analysis is then considered.

For video transmission, the video signal-to-noise equation is the starting point for the analysis of demodulated signal quality. This is discussed with reference to domestic industry standards. The effect of impulse noise is also considered, since this is often a limiting factor.

FDM-FM Message carriers require a two-step analysis, but the technique is very much the same as for video, except for the subjective weighting functions employed.

To illustrate the procedure, a sample analysis is presented for full transponder video transmission through a typical domestic satellite.

In general, the examples are selected for illustrative purposes, and, although an attempt was made to use parameters which are typical of the present state of the art, care must be taken in applying these results to a specific requirement. In particular, satellite characteristics must be obtained from the satellite operator for the specific transponder and for the geographic locations involved.

## SATELLITE LINK COMPONENTS

Figure 1 gives an illustration of the satellite transmission system. The link consists of a transmit earth station, satellite transponder, receiving earth station, and the space (and atmosphere) which lies between these components.

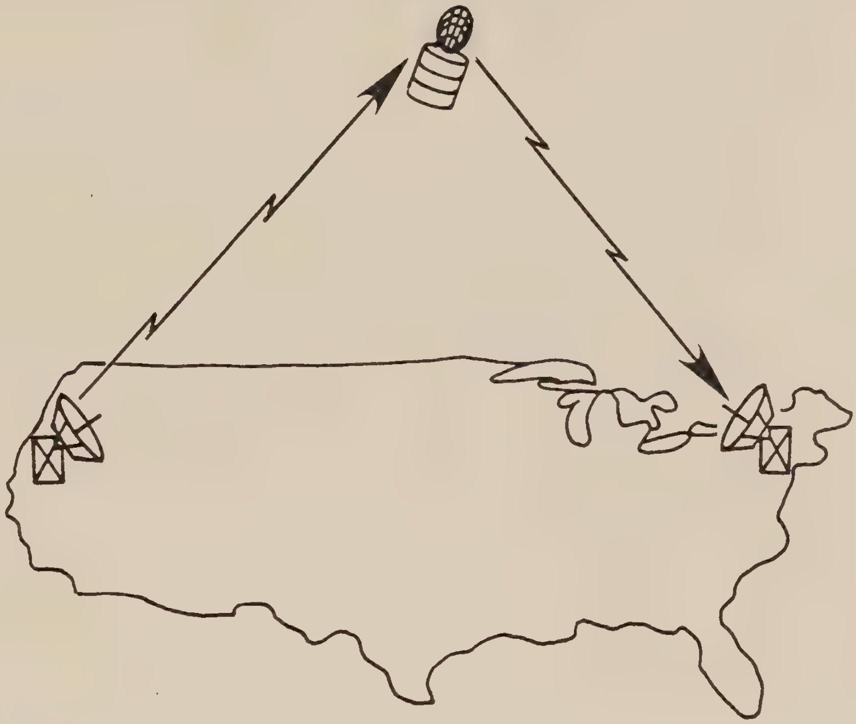


**Figure 1. Illustration of the Satellite Transmission System**

### Transmit Earth Station

In this discussion, the transmit earth station is characterized by the effective isotropic radiated power (EIRP) it produces. This of course is related to the transmitter power and the antenna gain at the transmit frequency, as indicated in Appendix A and in the paper which follows on earth station system design.

### Receiving Earth Station

For the purposes of this discussion, the receiving earth station is characterized by a figure of merit (G/T) and the IF bandwidth B. The techniques for analyzing the figure of merit for the system are described in the next paper. In Figure 2, a simplified block diagram is shown for the receiving system. Each element in the receiving chain can be assigned a noise temperature, which is a measure of the noise power contributed by the element per unit bandwidth.

These contributions are combined to reflect the noise power weighted by the gain distribution through the chain. In general, the noise temperature of the system is determined primarily by the antenna, the low noise amplifier, and the coupling components between these items. The addition of small losses, say by a long cable run, between the LNA and the antenna can result in significant degradation of G/T, and consequently in signal quality, for a very low noise system. On the other hand, the noise temperature (or noise

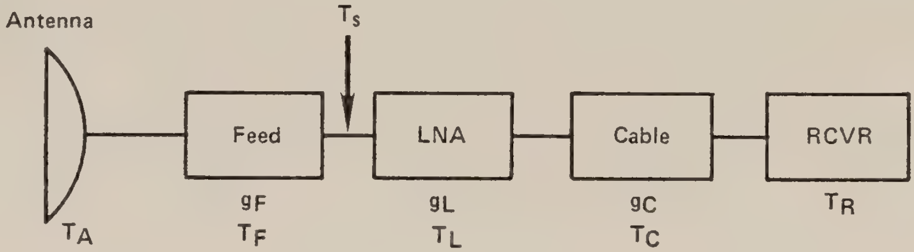



Figure 2. Receiving System Block Diagram

figure) of the receiver is of less consequence, because this factor is masked by the LNA gain.

The IF noise bandwidth for the receiver is normally chosen to be the smallest passband compatible with the FM deviation to be used for the transmission. For domestic full transponder video, this is about 36 MHz. Half transponder video normally requires a bandwidth of 17.5 MHz. International full transponder video through INTELSAT requires 30 MHz.

**Transmit/Receive Earth Stations**

For an earth station with transmit and receive capability, the receive performance is characterized in the same way as for the receive-only station. The figure of merit G/T must be adjusted to account for the addition of the transmit/receive diplexer and the transmit reject filter which are inserted between the antenna terminals and the LNA input.

**Satellite Transponder**

For commercial satellite communications, the orbiting spacecraft provides a one-hop carrier relay over a wide geographic area. For the domestic systems presently in use, the uplink signal is transmitted in a 36 MHz bandwidth near 6 GHz. This signal is received by the satellite, translated in frequency, filtered, amplified, and retransmitted in a 36 MHz band near 4 GHz. In a typical satellite of this sort, there are 12 to 24 transponders assigned within each frequency band.

Since the satellite serves as a transmit/receive station, it must be characterized by a G/T for the receive or uplink side, and by an EIRP for the transmit side. The EIRP is normally specified at the saturation point for the transponder power amplifier. For application where the satellite transponder output is not saturated, the actual output power expressed relative to saturation is called the Output Backoff.

Figure 3 shows the output power vs. input power for a typical TWT amplifier like those employed for the satellite transponder. The output saturation point is normally defined to be at the point where the output falls 5 dB below the linear extrapolation. Thus, when the transponder operates in the linear region - say, 6 dB output backoff - the input backoff must be 5 dB greater - for this example, 11 dB.

Transponder operation below saturation is required when multiple carriers are present, to control intermodulation. This topic is discussed, for example, in Reference 2.

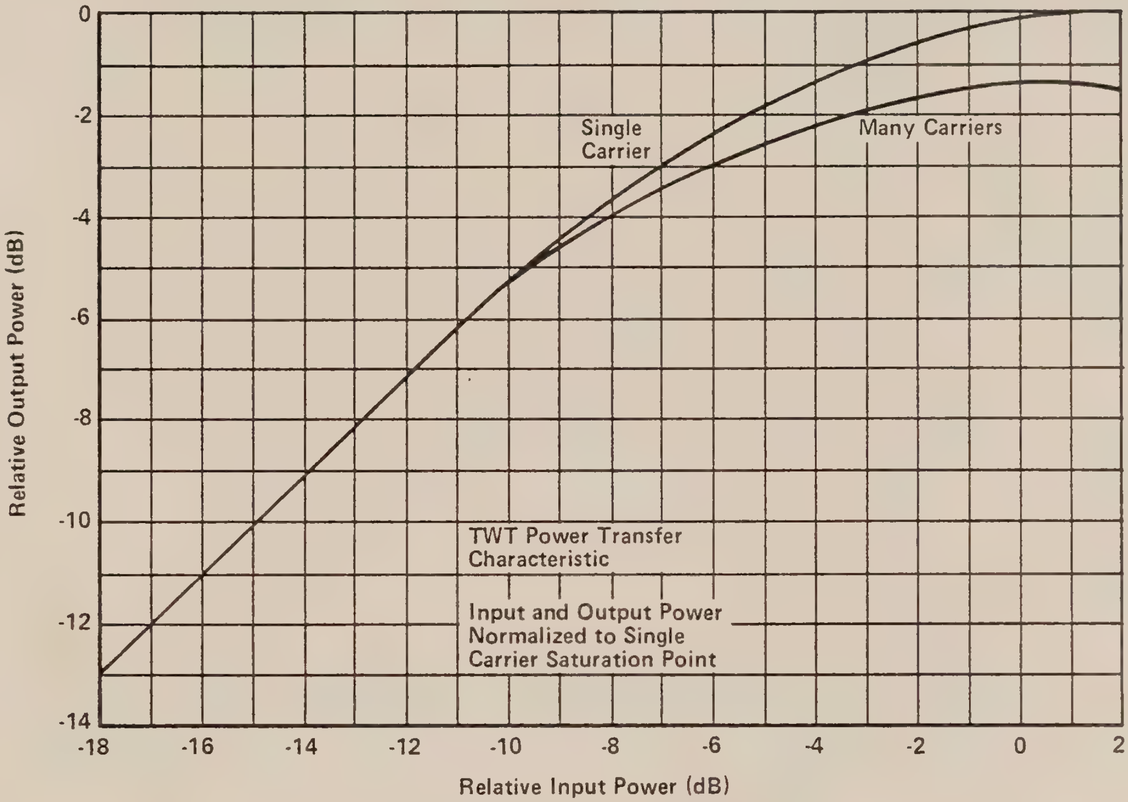



Figure 3. TWT Power Transfer Charachteristic

The satellite provides communications over a wide geographic area by using broad antenna beams for both transmit and receive functions. However, the antenna characteristics are not totally negligible; these result in geographic dependence for both EIRP and G/T. When presented graphically as contours on a terrestrial map, these produce the satellite "footprints", as shown in Figures 4 and 5 (typical data). These may vary from transponder to transponder, as well as from one satellite to another.

To relate the satellite input to output signals, the uplink flux density $\phi$ required at the satellite for transponder saturation is also specified. Since this is clearly related to the gain of the satellite receiving antenna, it also exhibits a geographical dependence like that shown in Figure 5.

Typical values for domestic satellites parameters in the continental U.S. are:

EIRP = 31 to 36 dBW

G/T = 0 to –6 dB/°K

$\phi_{SAT}$ = –81 to –84 dB/°K

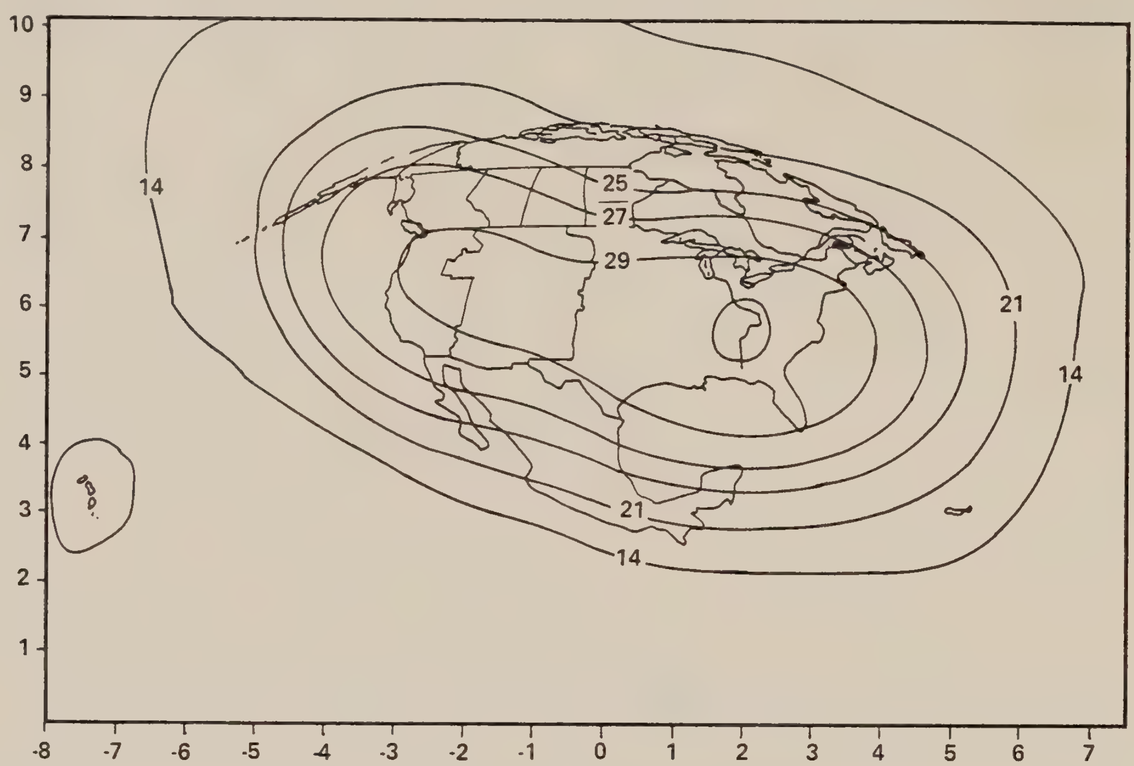



Figure 4. Typical EIRP Variation for a Domestic U.S. Satellite

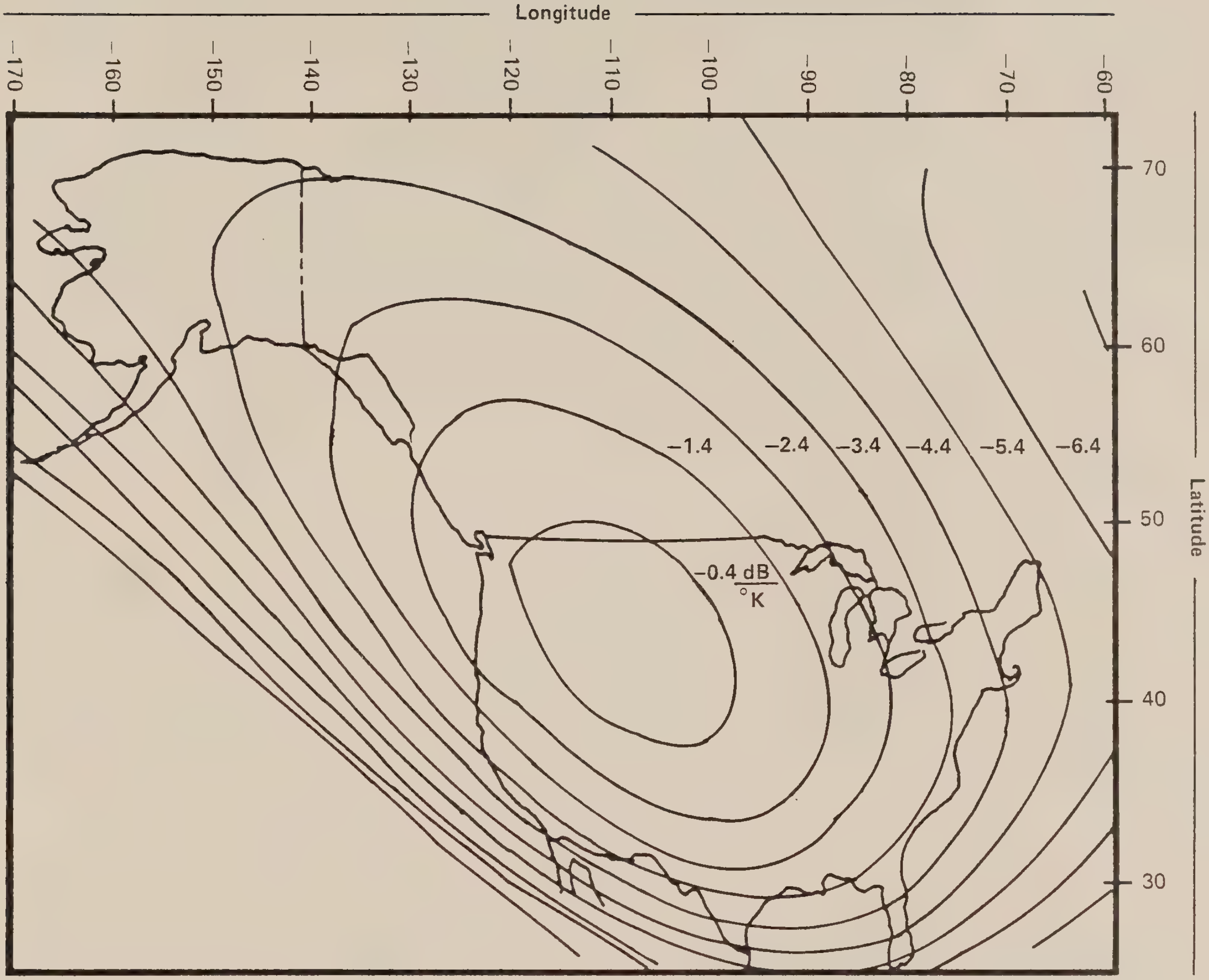



Figure 5. Typical Variation of G/T for a Domestic U.S. Satellite

**Space Loss and Atmospheric Attenuation**

As a signal travels from the satellite to the ground station it is dispersed into free space, refracted by the mediums into which it is spread and attenuated by the earths atmosphere. The two losses which reduce the signal level received from the satellite are dispersive losses, due to spherical wavefront spreading, and dissipative losses within the earths atmosphere.

The dispersive loss, or free space attenuation, originates from the spreading of the radiated energy on spherical wavefronts, as it travels from source to destination, as shown in Figure 6.

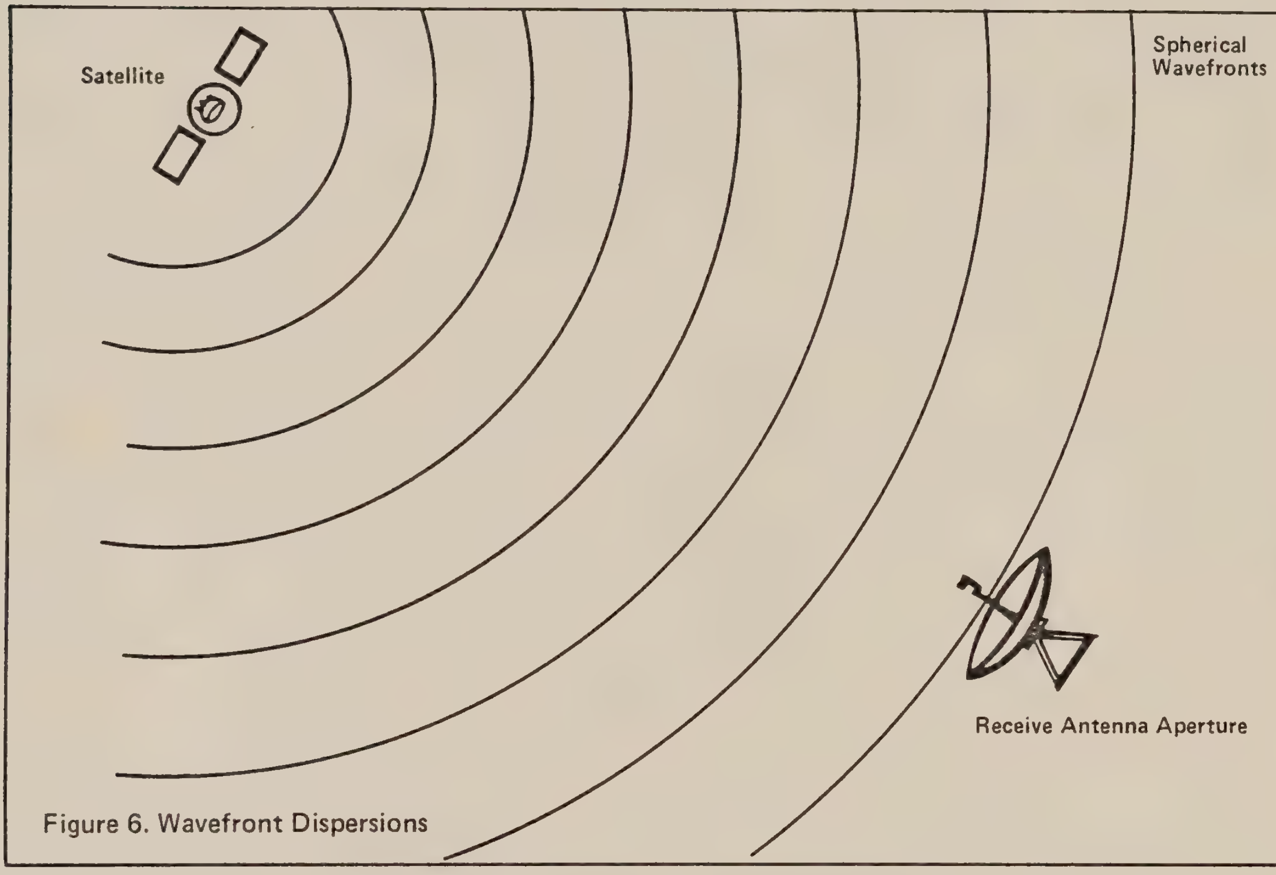



Figure 6. Wavefront Dispersions

In Appendix A, the origin of this loss is described mathematically, and the relationship of "space loss" to the link carrier-to-noise is shown. The free space attenuation is (in dB) the dimensionless factor,

$$L_s = 20 \log (4\pi \, r/\lambda)$$

where r is the distance from transmitter to receiver and $\lambda$ is the wavelength of the radiation.

In Appendix B, the orbit geometry for a geostationary satellite is described and the "space loss" is found to be

$$L_s = 185.05 + 10 \log (1 - 0.295 \cos H \cos \Delta L) + 20 \log f$$

where

Ls = Free Space Attenuation factor defined in the previous section, in dB

H = Latitude of earth station

$\triangle$L = Difference in longitude for earth station and satellite

f = Frequency in GHz

The frequencies used for satellite communications links were selected for minimum atmospheric absorption to provide reliable operation. Attenuation of RF signals within the earth's atmosphere is due mainly to the presence of oxygen and water. This loss can generally be assumed negligible for average atmosphere (i.e., a water vapor content of 10 gm/m$^3$.) However, during heavy rainfall periods it does degrade system performance by lowering the received carrier level and hence the carrier-to-noise ratio.

On an average sunny day the atmospheric attenuation would probably not exceed 0.1 dB. On rainy days the atmospheric attenuation is much more pronounced, as shown in Figure 7. (See Reference 3)

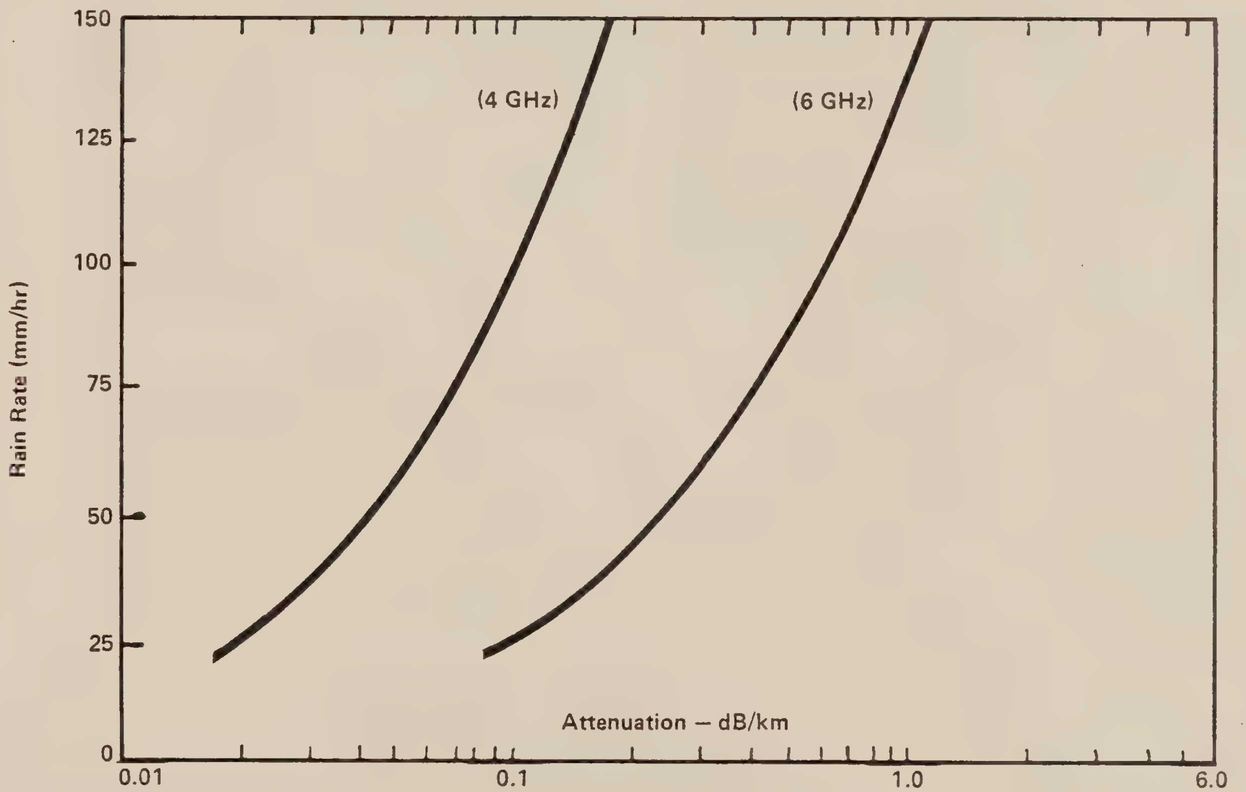



Figure 7. Attenuation vs. Rain Rate

To determine the effect of weather variations on the link performance, it is necessary to determine:

a. The probability for a given rainfall rate at the locations of interest, and
b. The effective rain path length for the elevation angle and rainfall rate, through which the RF signal must pass.

The rainfall rate probability varies considerably, of course; a typical set of rainfall data are given in Figure 8.

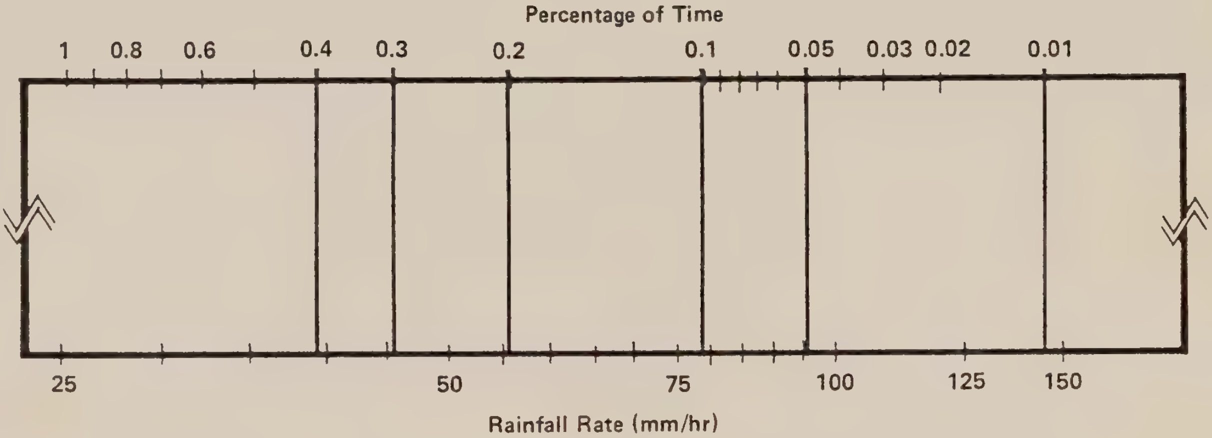



**Figure 8. Rainfall Rate vs. Percentage of Time (Typical Data for East Coast U.S. Site)**

Typical rain path length vs. rain rate and elevation angle are given in the following Table 1.

These typical path lengths assumes the rain is in the immediate area of the earth station. It is possible at 10-20° elevation angles for the antenna to look through longer rain path lengths as the rain cloud approaches. However, these cases have a relatively low probability of occurrance in most situations for the domestic U.S., so they are normally not considered as a significant factor.

For heavy rainfall rates and low elevation angles, the 4 GHz band attenuation could approach 0.9 dB. At the 6 GHz band, the attenuation for 150 mm/hr approaches 4 dB which would be a considerable transmit signal degradation.

It should be noted that according to the probability information given in Figure 8, this is a rare occurrance for most locations. Furthermore, for saturated transponder operation (as in the case of full transponder video) a 4 dB reduction in the uplink results in about 2 dB reduction for the downlink, through the TWT characteristic. Also, it is shown in the examples presented in this paper that the uplink C/N ratio is not a major contributor to the overall link noise, for most cases of this sort.

From these considerations it is possible to determine from the appropriate weather data and the loss factors given above, the atmospheric attenuation for the up- and down-links. This can be expressed as a degradation of the antenna noise temperature, or, more directly, entered in the link calculations as a budgeted loss.

## THE COMBINED SATELLITE LINK NOISE

With the basic parameters described in the previous sections, we can now apply the standard process of radio link analysis as described in Appendix A to the geostationary satellite path. We consider the downlink first, followed by the uplink. Then these results are combined with considerations of intermodulation and interference, when they apply, to determine the overall link performance.

### Downlink

From Appendix A, the downlink carrier-to-noise is

$$(C/N)_{down} = (EIRP)_{sat} - (Ls/)_{rx} + (G/T)_{rx} + 228.6 - 10 \log B - L_1$$

where

$(EIRP)_{sat}$ = effective isotropic radiated power for the satellite transponder, in dBW, for the geographic location of the receiving earth station, for the carrier considered.

$Ls/_{rx}$ = free space attenuation factor in dB for the downlink.

$(G/T)_{rx}$ = figure of merit in dB/°K for the receiving station

B = the reference noise bandwidth for the calculation (normally the receiver IF bandwidth) in Hz.

$L_1$ = the downlink fade margin for rain, pointing error, etc. in dB.

---

EXAMPLE: For a typical video receive only station, the G/T is about 26.8 dB/°K. Then for 34 dBW satellite EIRP, we get, using r = 24,600 mi, 1 dB link margin, and a 36 MHz bandwidth

$$(C/N)_{down} = (34 - 196.4 + 26.8 - 75.6 + 228.6 - 1) \text{ dB} = 16.4 \text{ dB}$$

---

It should be noted in relation for (C/N) given above, that

$$(EIRP)_{sat} = (EIRP)_{sat,\ max} - B_o$$

where

$(EIRP)_{sat,\ max}$ = saturated transponder EIRP in dBW

and $B_o$ = output backoff in dB.

**Uplink** The uplink C/N ratio is given by

$$(C/N)_{up} = (EIRP)_{tx} - (Ls)_{tx} + (G/T)_{sat} + 228.6 - 10 \log B - L_2$$

where

$(EIRP)_{tx}$ = transmitting earth station EIRP in dBW

$(Ls)_{tx}$ = free space attenuation factor for the uplink path in dB

$(G/T)_{sat}$ = satellite receiver figure of merit for the transmit station location, in dB/°K

B = reference bandwidth in Hz (must be the same as for downlink)

and $L_2$ = uplink margin for atmospheric attenuation pointing error, etc. in dB

---

EXAMPLE: For a 10 meter station (transmit gain $G_T$ = 53.5 dB) with a 1 kW transmitter, neglecting incidental losses, the EIRP is 83.5 dBW. Then for R = 24,600 mi slant range, a 1.5 dB link margin, and satellite G/T of −4.5 dB/°K, we get

$$(C/N)_{up} = (83.5 - 196.4 - 4.5 + 228.6 - 75.6 - 1.5)\ \text{dB} = 34.1\ \text{dB}$$

This example is noteworthy because it turns out to correspond approximately to the case of a saturated transponder, for most domestic satellites. Thus, the uplink C/N is much greater than that for the downlink (compare this example with the results in the sample calculation for the downlink). In other words, for full transponder FM video, the performance is dominated primarily by the downlink.

---

Many times the uplink must be considered in terms of the transponder backoff, as well. To do this, we re-express the $(C/N)_{up}$ in terms of the flux density and receiving antenna aperture, to obtain (See Appendix A)

$$(C/N)_{up} = \phi + \left[(G/T)_{sat} - 20 \log f - 21.45\right] + 228.6 - 10 \log B$$

where $\phi$ = uplink flux density for the transmitted signal at the satellite in $dBW/m^2$

$(G/T)_{sat}$ = figure of merit for the satellite receiver in dB/°K

f = uplink frequency in GHz

and B = reference IF bandwidth (same as for downlink) in Hz

Then the flux density $\phi$ can be replaced by

$$\phi = \phi_o - B_i + (G/T)_{sat/max} - (G/T)_{sat}$$

where

$\phi_o$ = saturation flux density for the transponder at the transmitter location.

$(G/T)_{sat/max}$ = main beam or maximum value (over all geographic locations) for the satellite G/T.

and

$B_i$ = input backoff in dB.

[The factors involving the satellite G/T are required to compensate for the fact that the factor $\phi_o$, as defined, varies according to the satellite receiving antenna pattern, but the flux $\phi$ does not.]

This yields the expression for the uplink C/N in terms of input backoff. By using the TWT transfer characteristic, $B_i$ can be related to the output backoff $B_o$; however, it should be noted that these are not identical quantities.

Note that the flux density can also be related to the transmitting earth station EIRP, i.e.,

$$\phi = (EIRP)_{Tx} - L_s + 20 \log f + 21.45 - L_2$$

or, in terms of the slant range R in meters

$$\phi = (EIRP)_{Tx} - 10 \log (4 \pi R^2) - L_2$$

This relationship can also be reversed to compute the required EIRP for the transmit station to achieve the desired backoff condition at the satellite.

---

EXAMPLE: For a saturated transponder, with $\phi_o = -81$ dBW/m² slant range 24,600 mi, and uplink margin 1.5 dB, the transmit earth station EIRP is

$$\begin{aligned}(EIRP)_{Tx} &= \phi_o + 10 \log (4 \pi R^2) + L_2 \\ &= (-81 + 163 + 1.5) \text{ dBW} = 83.5 \text{ dBW}\end{aligned}$$

For a 10 meter transmitting antenna, this corresponds to a transmit power of about 1000 watts (neglecting incidental losses).

---

**Interference** The uplink and downlink contributions are the principal factors of concern in the link calculation. However, there are often sources of interfering signals which must be considered in the analysis. For signals which are small relative to the carrier level (which is the usual case) the interference energy is usually added to the thermal noise as a power ratio C/I. This is the normal technique for handling interfering signals from an adjacent transponder for frequency reuse satellites, adjacent satellite signals, or terrestrial signals which fall in the receiver bandwidth. This presumes these signals to be a small contribution relative to the desired signal and to the link thermal noise. If this is not the case, the interference must be examined more carefully.

**Intermodulation** For multiple carriers in a transponder, the TWT non-linearity can lead to intermodulation products. These are normally small for good link design, and when they fall within the bandwidth of the receiver, they are treated in the same way as other interference signals. This is discussed in many publications, for example Reference 2.

## SUMMARY OF THE LINK ANALYSIS

The uplink, downlink, and interference contributions must be combined by the method described in Appendix A to obtain the final C/N ratio.

---

EXAMPLE: Using the results obtained for the uplink and downlink examples above, and a C/I of 20 dB, we get for the net link C/N:

$$C/N = 34\text{ dB} \oplus 16.4\text{ dB} \oplus 20\text{ dB}$$

$$= 10\log\left[\frac{1}{\frac{1}{2512} + \frac{1}{43.7} + \frac{\phantom{1}}{100}}\right]$$

$$= 10\log 30$$

$$= 14.8\text{ dB}$$

This is equivalent to a carrier-to-noise density

$$C/N_o = 90\text{ dB-Hz} = 30\text{ dB - MHz}$$

---

For a satellite link with multiple carriers, the consideration of intermodulation requires calculations of link C/N for various values of backoff, to determine the optimum operating point, since intermodulation increases as the transponder is pushed toward saturation.

For digital links, the bandwidth B in the above calculations is replaced by the transmitted bit rate to obtain the energy per bit per noise density ratio $E_b/N_o$, which is related to digital bit-error-rate performance. This is discussed briefly in Appendix A.

**EVALUATING THE BASEBAND PERFORMANCE**

Using the results of the link analysis, we next consider the method for determining the effect of the link noise on the transmitted signal. This is considered for FM-video with or without audio subcarrier, for FDM-FM Message, and for digital (PSK) transmission.

**FM-Video**

The video performance must be examined for two distinct degradations:

a. Thermal noise in the baseband, which is similar to the noise encountered in broadcast TV, and
b. Impulse noise, which is a phenomenon associated with FM threshold effects.

Impulse noise and FM threshold depend on the carrier-to-noise ratio for the FM receiver (before the FM demodulator) which can be projected from the link analysis using the IF bandwidth of the receiver. The threshold region depends somewhat on the receiver design, but occurs near $C/N \leqslant 11$ dB.

### Signal-to-Noise Above Threshold

Above the FM threshold region, only the first factor is of significance. In this case, the video signal-to-noise is given by

$$(S/N) = (C/N_o) \frac{12\,(\Delta F_s)^2}{b_n{}^3}$$

Where

$C$ = carrier power (watts)

$N_o$ = noise power density at that point in the receiver where C is measured = $kT_s$ (watts/MHz)

$k$ = Boltzmann's constant = $1.3806 \times 10^{-17}$ W/MHz/°K

$T_s$ = system operating noise temperature referred to that point in the system where C is measured (°K)

$F_s$ = half of the peak-to-peak deviation produced by that part of the video waveform which is defined to be the "signal" (MHz)

$b_n$ = noise bandwidth of the baseband filter function (representing the combination of the de-emphasis network, measurement band-limiting filter, and weighting network [when used]) with respect to "triangular" noise (MHz). This can be computed from:

$$b_n = \left[ 3 \int_0^F f^2 \left| H(f) \right|^2 df \right]^{1/3}$$

$H(f)$ = product of de-emphasis, bandlimiting filter, and weighting (if used) transfer functions

$F$ = an integration limit frequency high enough so that $H(f)$ may be considered zero above F.

The definition of (S/N) and a derivation are given in Reference 1, a copy of which follows this paper.

In decibels, (S/N) is 10 times the logarithm of the numeric ratio expression.

Note that (S/N) is not a function of IF bandwidth or modulating frequency. The relation (or any of its variants) is applicable, however, only when the IF bandwidth is at least adequate to support the signal.

Since the video signal is a complex waveform and a variety of emphasis and noise weighting functions can be used in principle, specific standards have been established to provide guidance in evaluating this S/N ratio. The S/N equation presented is sufficiently general to accomodate any standard by specifications of the appropriate $\Delta F_s$ and $b_n$. The standard presently used for most domestic satellite video transmissions is set by CCIR Rec. 421-3, (Ref. 4). It has been adopted by the Network Transmission Committee of the Video Transmission advisory committee, a joint committee of television network broadcasters and the Bell System. For this standard, the "signal" is taken to be the luminance part of the video waveform, such that

$$\Delta F_s = 0.714 \, \Delta F_v$$

Where

$\Delta F_v$ = half the peak-to-peak deviation produced by the video waveform including sync tips.

For this standard, the unweighted bandwidth is

$$b_n = 3.357 \text{ MHz}$$

and the bandwidth with noise weighting is

$$b_n' = 1.574 \text{ MHz}$$

The subjective weighting advantage for FM transmission is thus

$$30 \log \frac{b_n}{b_n'} = 9.9 \text{ dB}$$

For a more complete discussion of the standards and recommendation, see Reference 1.

---

EXAMPLE: For full transponder video with $\Delta F_v$ = 11 MHz transmitted through the satellite link analyzed in the previous section, we will compute the S/N projected for the received signal with and without noise weighting.

Without noise weighting, we have

$$\begin{aligned} S/N &= C/N_o + 20 \log \Delta F_s - 30 \log b_n + 10 \log 12 \\ &= 30 + 20 \log (0.714 \times 11) - 30 \log (3.357) + 10.8 \\ &= 42.9 \text{ dB} \end{aligned}$$

With noise weighting to account for the subjective effect of the noise, we get

$$S/N = (42.9 + 9.9) \text{ dB} = 52.8 \text{ dB}$$

---

Many variations for the video S/N equation exist. The subtle differences in form from one version to another can lead easily to erroneous results. To avoid this confusion, no alternate forms for this calculation are presented here.

### Threshold and Impulse Noise for FM-Video

As the C/N ratio (for the actual noise bandwidth of the receiver) decreases the performance of an FM discriminator begins to deviate from the predictions of the video S/N equation. This is a result of impulse noise, which is more noticeable subjectively than the change in RMS signal-to-noise might indicate. The region where the signal-to-noise begins to depart from the equation above is called the "threshold region."

Near threshold, the preceding analysis is not sufficient in itself to describe the quality of the received signal. In this region, the thermal noise peaks in the IF band have a finite probability to exceed the carrier level, resulting in an apparent phase inversion in the composite signal. The FM discriminator then reacts to this with a rapid transition, which results in a baseband transient or impulse disturbance. The threshold for the onset of this phenomena depends on the nature and design of the Video Demodulator (the term "threshold" is used in a variety of meanings for video demodulators, and this must be examined carefully for the particular problem under consideration). For standard equipment presently in use in commercial satellite communications, the impulse noise becomes noticeable first at about 11 dB C/N.

Threshold extension techniques allow operation into the threshold region without drastic degradation. Threshold effects and threshold extension techniques are discussed in a subsequent paper.

### Audio Subcarrier for Video

Television audio is generally transmitted through the satellite link by means of an FM subcarrier which modulates the main carrier, in addition to the video baseband. In the video receiver, main demodulator output contains the sum of video plus subcarrier. This signal splits to feed the roofing filter which separates the video baseband, and (along the other path) to drive the audio subcarrier discriminator. This is shown in Figure 9.

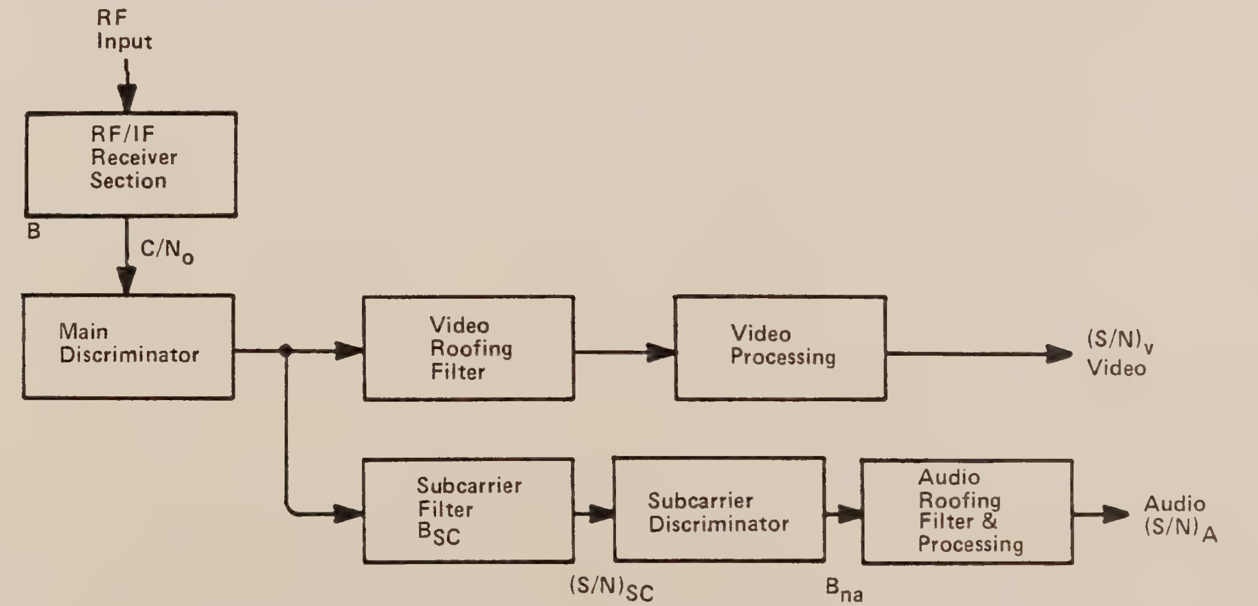



Figure 9. Simplified Video Receiver with Audio Subcarrier Processing

The subcarrier signal-to-noise ratio ahead of the subcarrier discriminator is given by

$$(S/N)_{sc} = 1/2\ (C/N_o) \frac{\Delta F_c^2}{f_{sc}^2 \quad B_{sc} \left[ 1 + \frac{1}{12} \left( \frac{B_{sc}}{f_{sc}} \right)^2 \right]}$$

where

$(C/N_o)$ = carrier-to-noise density (before main discriminator) in MHz

$\Delta F_c$ = peak deviation of the main carrier by the subcarrier in MHz

$f_{sc}$ = subcarrier frequency (usually 5.8 or 6.2 MHz)

$B_{sc}$ = subcarrier filter noise bandwidth in MHz

The quantity in brackets in the denominator is negligible for all schemes presently in use.

---

EXAMPLE:
For a subcarrier with

| | | |
|---|---|---|
| Subcarrier deviation | $\Delta F_c$ | = 1 MHz |
| Subcarrier Frequency | $f_{sc}$ | = 5.8 MHz |
| Subcarrier Filter BW | $B_{sc}$ | = 0.5 MHz |

the subcarrier S/N before the discriminator is

$$S/N = 30\ \text{dB} - \text{MHz} + 20 \log \left( \frac{\Delta F_c}{f_{sc}} \right) - 10 \log B_{sc} - 3\ \text{dB}$$

$$= (30 - 15.3 + 3 - 3)\ \text{dB} = 14.7\ \text{dB}$$

---

Since this is an FM signal, this must again be examined relative to FM threshold, before the analysis is continued. For audio signals, again the threshold region is around 10-11 dB carrier-to-noise ratio before the discriminator.

The program channel (audio) signal-to-noise ratio is then for signals above threshold, given by

$$(S/N)_{pgm} = (3/4) \left( \frac{C}{N_o} \right) \frac{\Delta F^2{}_c}{f^2{}_{sc}} \quad \frac{\Delta F^2{}_{sc}}{B^3{}_{na}}$$

where

$\Delta F_{sc}$ = peak deviation of the subcarrier by the program test tone.

$B_{na}$ = noise bandwidth of the audio baseband and filter function (including de-emphasis, psophometric weighting, and band-limiting filtering, with respect to triangular noise.)

For the case of no emphasis or weighting and an ideal rectangular band-limiting filter from 50 Hz to 10 kHz, the noise bandwidth $B_{na}$ would be

$$B_{na} = \left[(10{,}000)^3 - (50)^3\right]^{1/3} \text{ Hz} \approx 10 \text{ kHz}$$

For CCITT J.17 de-emphasis normalized to a 0 dB crossover at 800 Hz, CCITT P.53 weighting and an ideal 10 kHz bandlimiting filter, $B_{na}$ = 6.344 kHz. For a more realistic bandlimiting filter, this value would be slightly larger, but the difference would be relatively small because of the rapid roll-off of the weighting network.

EXAMPLE: Using the latter case we get, for the same subcarrier bandwidth, frequency, and main carrier deviation as before, with subcarrier peak deviation $\Delta F_{sc}$ of 100 kHz,

$$(S/N)_{pgm} = 60 \text{ dB (kHz)} + 20 \log \frac{1}{5.8} + 20 \log\left(\frac{100}{6.344}\right) - 10 \log (6.344) + 10 \log (3/4)$$

$$= (60 - 15.3 + 24 - 8 - 1.24) \text{ dB} = 59.4 \text{ dB}$$

**FDM Message Carriers**

For the FDM Message Carrier, the baseband signal consists of independent single-sideband AM signals translated in frequency and combined to produce a composite signal. This is used to frequency modulate the main carrier. Since this is normally used for transmitting narrowband voice channels (300-3400 Hz), the effect of pre- and de-emphasis is to adjust the modulation level from channel to channel, for test tone. The emphasis characteristic is given in Reference 5.

The demodulator process is similar to that for the TV audio subcarrier, except that the signal is effectively filtered through an audio bandwidth and translated down to baseband, rather than going through the second stage of FM demodulation as for the subcarrier.

Thus, if the pre-discrimination S/N equation is used with $B_{sc}$ replaced by the voice-channel bandwidth, the signal-to-noise ratio for the baseband channel is obtained directly.

It is customary for FDM-FM signals, to use RMS (rather than peak) deviations for calculations. This leads to the revised S/N equation for channel i

$$(S/N)_i = (C/N_o) \frac{\Delta F^2_{i,rms}}{f_i^2 \, B \left[1 + \frac{1}{12}\left(\frac{B}{f_i}\right)^2\right]}$$

where

$\Delta F_{i,\,rms}$ = RMS deviation for test tone in channel i (adjusted for pre-emphasis effects)

$f_i$ = center frequency for channel i

B = channel baseband bandwidth (normally 3.1 kHz)

This expression gives the signal-to-noise ratio for unweighted noise. If a psophometric (CCITT P.53) weighting is introduced, the resulting S/N can be obtained using the psophometric advantage computed from the noise spectrum shape, channel bandwidth, and (P.53) weighting function. Since the noise is nearly flat across a multiplexed voice channel bandwidth, this is approximately equal to the advantage for flat noise, which is 2.5 dB (with an ideal filter).

## PSK Digital Signals

For digital signals, the baseband performance is measured by the bit error rate. For data transmission, this must be typically better than 1 in $10^7$. This error rate is related to the ratio of energy-per-bit-per-noise-density ($E_b/N_o$) which is equivalent to the C/N ratio in a bandwidth equal to the transmission bit rate. (See Appendix A.)

Figure 10 shows theoretical curves for digital bit rate performance vs. $E_b/N_o$, both with and without a rate −7/8 forward-error correction coder with threshold decoding. In actual practice, digital transmission equipment can come within 1-2 dB of these curves for continuous data transmission.

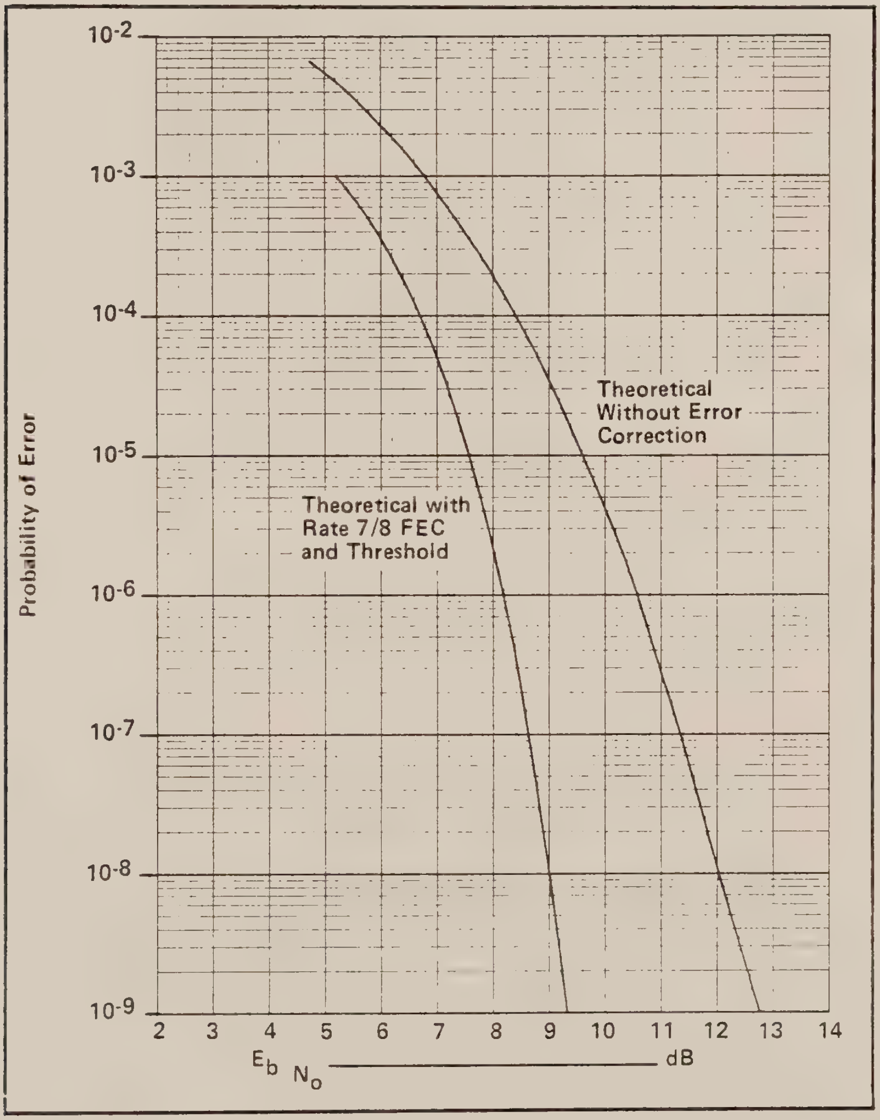



Figure 10. Theoretical BER Performance vs. $E_b$ $N_o$

# APPENDIX A

## LINK ANALYSIS FUNDAMENTALS

Consider a transmitting station emitting power $P_T$ with gain $g_T$ as illustrated in Figure A-1. At a distance r from the transmitter, the transmitted flux density $\phi$ along the beam axis is

$$\phi = \frac{P_T g_T}{4\pi r^2}$$

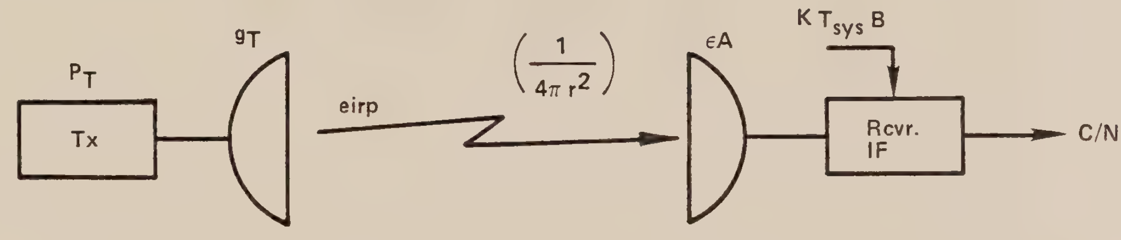



Figure A-1. RF Link Diagram

If a receiving antenna of area A and with efficiency $\epsilon$ is located in this flux density, the received carrier level is, at the antenna output

$$C = \phi A = \frac{P_T g_T \epsilon A}{4\pi r^2}$$

The equivalent noise power at this point in the IF bandwidth B is determined from the system noise temperature $T_{sys}$ referenced to the antenna output,

$$n = k\, T_{sys} B,$$

where k = Boltzmann's constant

Then the resulting ratio of carrier-to-noise power is

$$c/n = \frac{P_T g_T \epsilon A}{4\pi r^2\, k\, T_{sys} B}$$

The effective aperture of the receiving system ($\epsilon A$) is related to the antenna gain at that frequency - from antenna fundamentals

$$\epsilon A = \frac{g_R\, \lambda^2}{4\pi} = \frac{g_R\, c_o^2}{4\pi\, f^2}$$

where

$c_o$ = the speed of light

(Note that the ratio $\frac{g_R}{f^2}$ is independent of frequency for the range of interest to the extent that the efficiency $\epsilon$ is not frequency-dependent.)

Using this relation for the effective area, we get

$$c/n = \frac{P_T g_T g_R c_o^2}{(4\pi)^2 r^2 f^2 k\ T_{sys}\ B}$$

The product $P_T g_T$ is usually referred to as the "effective isotrophic radiated power", or EIRP, for the transmitting system. The ratio $(g_R / T_{sys})$ is normally used as the figure-of-merit for the receiving system. This ratio is independent of the point of reference chosen for defining the individual terms $g_R$ and $T_{sys}$. Separating the various factors, we can rewrite the received (c/n) ratio as:

$$c/n = (\mathrm{EIRP}) \left(\frac{1}{4\pi r^2}\right) \left(\frac{c_o^2}{4\pi f^2}\right) \left(g_R / T_{sys}\right) \left(\frac{1}{B}\right) \left(\frac{1}{k}\right)$$

The second and third factors $\left(\frac{1}{4\pi r^2}\right) \left(\frac{c_o^2}{4\pi f^2}\right)$

are often combined as a unitless free space attenuation factor, although clearly the latter portion has no direct origin in spatial losses. Often the factor B is omitted (that is, B = 1 Hz is used) to determine the carrier-to-noise density ($c/n_o$.) In some cases the fixed constant k is dropped entirely and the calculation is carried out for C/T rather than $c/n_o$.

In digital communications the normalized SNR parameter is denoted $E_b/N_o$ where $E_b$ is energy-per-bit and $N_o$ is noise spectral density. Now $E_b$ is a product of power and time thus:

$$E_b\ /\ N_o = \frac{CT'}{N_o} = \frac{\frac{C}{N_o}}{T'}$$

where T′ is a bit period and T′ equals the transmitted bit rate R′, so

$$E_b / N_o = \frac{C}{N_o R'}.$$

But $N_o R'$ is the noise power N in a bit rate bandwidth so that

$$E_b / N_o = C/N$$

where N is noise power measured in a bit rate bandwidth.

The link (c/n) calculations are almost always carried out in dB, rather than directly from the relations above, because of the cumbersome numbers involved. Rewriting accordingly, we get

$$C/N = 10 \log (c/n) = \mathrm{EIRP} - S + (G/T)_R - 10 \log B + 228.6$$

where

$$EIRP = 10 \log (eirp) \text{ in dBW}$$

$$S = 10 \log \frac{c_o^2}{(4\pi)^2 r^2 f^2} = 96.58 + 20 \log r_{mi} + 20 \log f_{GHz}$$

$$= \text{"space loss" in dB}$$

$$(G/T)_R = 10 \log (g_R / T_{sys})$$

(Note this is a single algebraic quantity when expressed in dB/°K)

$$B = \text{IF bandwidth in Hz}$$

In some cases, it is more convenient to deal with the spatial factor $4\pi r^2$ separately, and combine the third and fourth factors in the expression for c/n to obtain the effective aperture $\epsilon A$. In this case, the expression for C/N in dB becomes

$$C/N = EIRP - L + (A/T) - 10 \log B + 228.6$$

where

$$L = 10 \log (4\pi r^2)$$

$$= 20 \log r_{mi} + 75.13 \quad (r \text{ in mi}, L \text{ in dBm}^2)$$

$$(A/T) = 10 \log (\epsilon A / T_{sys}) = (G/T)_R - 20 \log f_{GHz} - 21.45 \text{ dBm}^2$$

For two cascaded links, the C/N ratios must be combined to determine the net effect of a transmission through the link. For the cascaded links, if each separately has a carrier-to-noise ratio $(c/n)_1$ and $(c/n)_2$ respectively (NOT expressed in dB) then the resulting ratio $(c/n)_{tot}$ for this link is

$$(c/n)_{tot} = \frac{1}{\dfrac{1}{(c/n)_1} + \dfrac{1}{(c/n)_2}}$$

Note that this combining operation cannot be accomplished directly with ratios expressed in dB. Rather, the c/n ratios in dB must first be re-expressed in non-logarithmic form, summed according to the above rule, and then (if required) re-expressed in dB.

This summing rule can be extended to any number of cascaded or independent contributions, to allow combination of several factors in a given analysis directly, by adding additional terms in the denominator above.

---

EXAMPLE: It is worthwhile to consider an example of this combination formula, to understand the consequences. Suppose there are two cascaded links, with

$$C/N_1 = 10, (c/n)_2 = 20 \text{ dB}.$$

Then

$$(c/n)_1 = 10, (c/n)_2 = 100 \text{ and}$$

$$c/n = \frac{1}{\frac{1}{10} + \frac{1}{100}} = \frac{1}{.11} = 9.09$$

or $$C/N = 10 \log (9.09) = 9.6 \text{ dB}$$

Thus the obvious result is obtained; that is, the smaller c/n dominates and the larger c/n ratio (20 dB in this example) has only a small effect.

Another special case of interest is two equal (c/n) links in cascade. In this case, it can be shown directly that the resulting cascaded link c/n is 3 dB lower than the individual links considered separately.

---

One note of caution is worth mentioning here: The c/n summation is valid only if these factors are computed for the same bandwidth B, which is normally the bandwidth for the final IF in the video receiver. This procedure can also be applied of course for a 1 Hz bandwidth the sum the contributions to the carrier-to-noise density, $c/n_o$.

# APPENDIX B

## GEOSTATIONARY SATELLITE ORBIT GEOMETRY

For a geostationary satellite, the orbit is a circle lying in the equatorial plane which, from simple mechanics has a radius

$$R = 6.6208\ R_o$$

where $R_o$ is the radius of the earth (3959 statute miles). The location of the satellite is specified by the corresponding longitude coordinate, $L_{sat}$. For a station at a given latitude and longitude, the slant range r from the satellite to the station is found to be

$$r = 26509\ [1 - 0.295 \cos(H) \cos(\triangle L)]^{1/2} \quad \text{(statute mile)}$$

converting from miles to meters

$$r = 42.658 \times 10^6\ [1 - 0.295 \cos(H) \cos(\triangle L)]^{1/2} \text{ meters}$$

where

$$\triangle L = \text{station longitude - satellite longitude}$$
$$H = \text{station latitude}$$

The corresponding spatial loss factor is

$$\begin{aligned} \ell s &= 10 \log (4\pi r^2) \\ &= 163.6 + 10 \log [1 - 0.295 \cos(H) \cos(\triangle L)]^{1/2} \text{ dB (meters)} \end{aligned}$$

The free space attenuation is given by

$$\begin{aligned} L_s &= 10 \log (4\pi r / \lambda)^2 \\ &= 10 \log (4\pi r^2) + 10 \log (4\pi / \lambda^2) \end{aligned}$$

Now

$$\begin{aligned} \lambda &= c/f \\ &= 3 \times 10^8 \text{ meters} / f_{GHz} \times 10^9 \end{aligned}$$

where $f_{GHz}$ = frequency in GHz

Therefore

$$\begin{aligned} L_s = {} & 163.6 + 10 \log [1 - 0.295 \cos(H) \cos(\triangle L)]^{1/2} \\ & + 10 \log (139.63) + 20 \log(f) \end{aligned}$$

$$L_s = 185.05 + 10 \log [1 - 0.295 \cos(H) \cos(\triangle L]^{1/2} + 20 \log (f_{GHz})$$
$$r = 26509\ [1 - 0.295 \cos(H) \cos(L\text{-}L_{sat})]^{1/2} \text{ (statute mile)}$$

Reference

1. L. Clayton, "FM Television Signal-to-Noise Ratio", IEEE Transactions on Cable Television, Vol. CATV-1, No. 1, October 1976.
2. R.J. Wescott, "Investigation of Multiple FM/FDM Carriers Through a Satellite TWT Operating Near to Saturation," Proc. IEEE, Vol. 114, No. 6, June 1967.
3. D.C. Hogg and R.A. Semplak, "The Effect of Rain and Water Vapor on Sky Noise at Centimeter Wavelengths," The Bell System Technical Journal, 1331-1448 (September 1961).
4. C.C.I.R. (International Radio Consultative Committee), "Transmission of Sound Broadcasting and Television Signals over Long Distances (CMTT)", XIIIth Plenary Assembly, Vol. XII, International Telecommunication Union, Geneva, 1975, pp. 21-41.
5. C.C.I.R. (International Radio Consultative Committee), Recommendation 464, "Pre-Emphasis Characteristic for Frequency Modulation Systems," XIIIth Plenary Assembly, Vol. IV, International Telecommunication Union, Geneva, 1975, pp. 64-71.

# THE IMPACT OF EARTH STATION CONFIGURATION ON SYSTEM PERFORMANCE

Ray Stuart
Manager, Systems Engineering
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## THE IMPACT OF EARTH STATION CONFIGURATION ON SYSTEM PERFORMANCE

### Introduction

This paper presents system design consideration which can impact the performance of a video, telephone, or data earth station.

This discussion specifically involves two earth station parameters, G/T and EIRP, and the impact of system configuration on those parameters.

G/T (System figure of Merit)

As described in the reference, Link Analysis, the quality of a signal such as video is a function of S/N which is in turn a function of C/N which is a function of G/T. That is,

$$Qp = F\ (S/N) = F\ (C/N) = F\ (G/T)$$

or,

$$Qp = F\ (G/T)$$

where

Qp = Picture quality for video

S/N = is output signal to noise ratio

C/N = is the input carrier to noise ratio

G/T = Gain of the receiving antenna minus the system noise temperature in decibels.

Therefore it is apparent that in order to maximize picture quality then G/T should be maximized.

Earth Station G/T can be defined as follows:

$$G/T_S = G_N - T_S \text{ (in dB)}$$

where

$G_N$ = the net antenna gain and is defined by

$G_N = G_A - L_V$ (dB)

where

$G_A$ = the gain of the antenna at the Orthomode Transducer (OMT) output ports and

$L_V$ = effective gain loss due to Voltage Standing Wave Ratio (VSWR)

and where

$T_S$ = receive system noise temperature (°K)

$T_S$ is defined as follows:

$$T_S = T_A + T_V + T_{LNA} + T_L$$

where

$T_A$ = antenna noise temperature referenced to the LNA input

$T_V$ = noise temperature contribution due to antenna and LNA VSWR

$T_{LNA}$ = LNA noise temperature

$T_L$ = post-LNA noise temperature contribution (K), due cable length and downconverter

Generally the antenna temperature is set by the design of the antenna and the elevation "look" angle. The same holds true for the LNA and VSWR contributions; that is these values are generally set by the system design.

The post-LNA noise temperature contributions, referenced to the LNA input, can be determined, from:

$$T_L = (P\ NF - !)\ T_o/G_{LNA}$$

where

P = insertion loss of cable between the LNA and downconverter

NF = downconverter noise figure

$G_{LNA}$ = LNA gain

$T_o$ = ambient temperature

The post LNA contribution can change depending upon the earth station configuration. That is, the post LNA contribution increases with the length of cable between the video receiver and the LNA. This in turn causes a decrease of the system G/T.

Figure 1 shows how the G/T of an earth station degrades with length of cable between the LNA and the receiver. Both 1/2 inch and 7/8 inch air dielectric cable are shown. Since 1/2 inch cable is lower cost it should be utilized for runs up to about 200 feet. For longer runs 7/8 inch cable should be used. After about 500 feet it becomes necessary to add on amplifier between the LNA and receiver to overcome the cable loss and its contribution to system noise temperature.

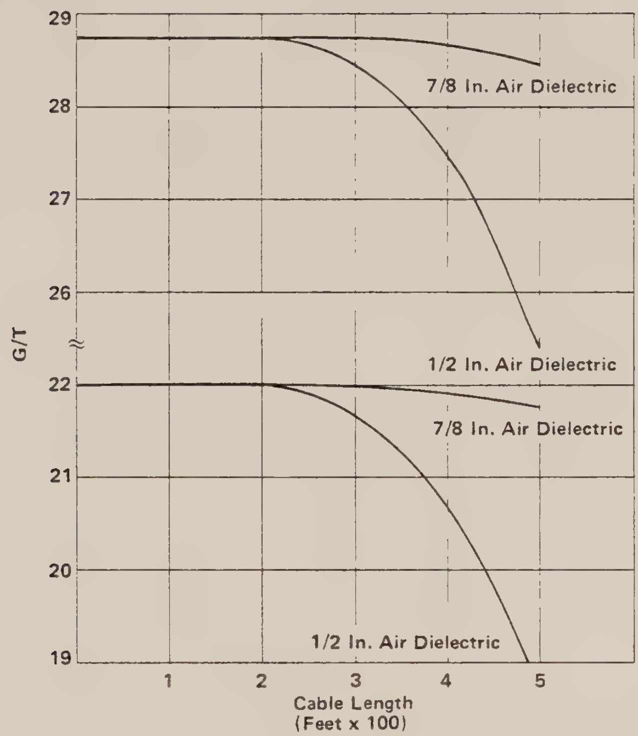



**Figure 1. System G/T versus Post LNA Cable Length**

**EIRP (Effective Isotropic Radiated Power)**

The EIRP of an earth station is a function of the transmitter size, the antenna gain and the system configuration. That is:

$$EIRP = P_T + G_A - L$$

where

$P_T$ = output power transmitter
$G_A$ = Antenna Gain relative to an Isotropic Radiator
$L$ = Loss between transmitter and the antenna

Both the antenna gain and transmitter output power and generally set by the products selected. That is the antenna gain is generally determined by the size (5 meter, 10 meter, etc.) and the output power of the power amplifier is determined by that selected.

The loss (L) between the antenna and the transmitter is dependent upon system configuration. Again, as with the cable between the LNA and receiver, the length of the waveguide between the antenna affects the EIRP. Therefore, if possible, the site layout should be such that the waveguide run between the antenna and transmitter is as short as possible.

**Site Layout** In general the site layout is determined by the size of the earth station and the amount of available space for the earth station site. The antenna and electronics equipment should be co-located, if possible, to prevent long, costly, cable runs. If it is not possible to locate the electronics equipment with the antenna, it is advisable to run large diameter air dielectric RF cable from the LNA, located in the antenna hub, to the receiver rack, located in the equipment shelter.

Cable runs of this type — 300 to 400 feet — have been used in several stations. However, for runs of 1,000 feet or more, amplifiers must be placed in line with the cable and spaced at regular intervals. Failure to do this will result in receiver performance degradation (G/T). Placement of the amplifiers is extremely critical if this problem is to be avoided.

Transmit stations should not have the HPA located more than 100 feet from the antenna. This is because of losses in the 6 GHz waveguide. These losses can be extremely inefficient in terms of power loss. Long waveguide runs could require larger sized HPA's. This would be a costly midtake. However, the exciters may be located some distance from the HPA's if sufficient drive is available to excite the HPA's to the required output power. This might allow a reduction in the shelter size necessary at the antenna location.

Site layouts for several different types of earth stations will now be considered. These layouts are typical of those now installed in the comestic satellite service.

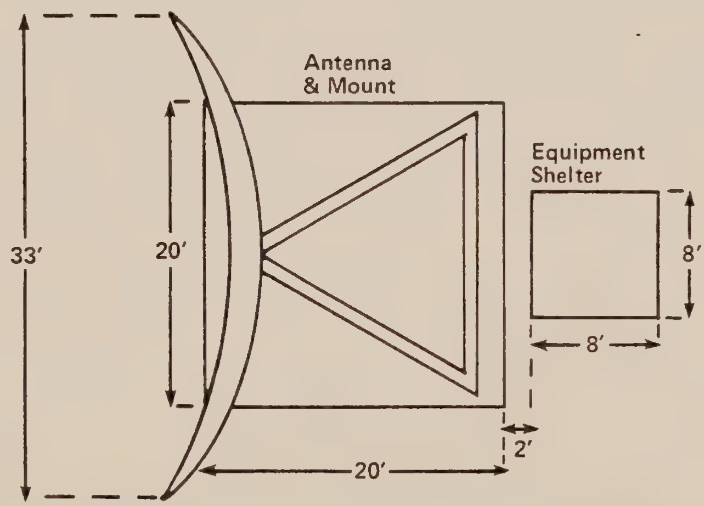



Figure 2. Typical TV R/O Site Layout

Figure 2 shows a typical site layout for a small TV R/O 10 meter earth station. Generally the TV R/O GCE includes only one or two video receivers and possibly a protection switch. Thus, the equipment shelter size can be

kept to a minimum. If a 5 meter antenna were used instead of the 10 meter, the antenna pad size would be 9 x 9 feet.

Figure 3 shows a typical site layout for a redundant T/R earth station. An equipment layout for the shelter is shown in Figure 4. This layout allows room for expansion to four uplinks along with room for a workbench or desk.

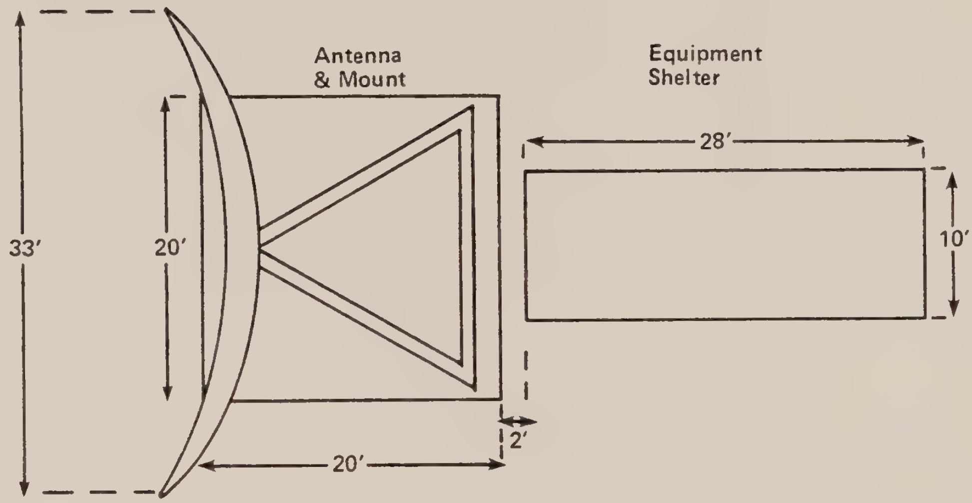



Figure 3. Typical Redundant T/R Earth Station Layout

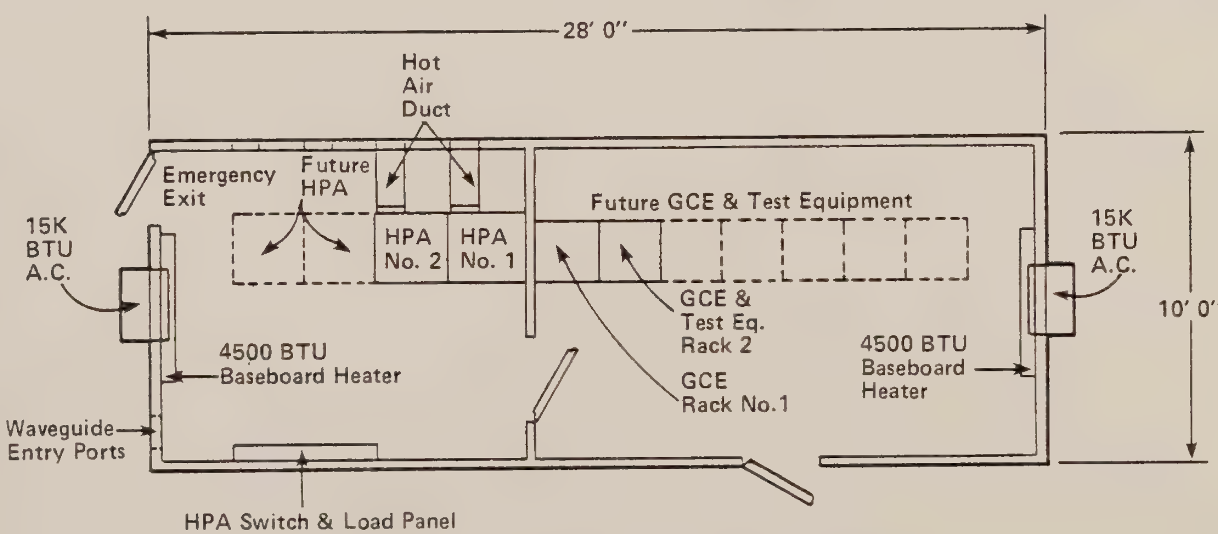



Figure 4. Electronics Equipment Shelter Floor Plan

Figure 5 shows a similar layout in an 8 x 16-foot builing. This layout would allow little convenient expansion capability and almost no work room.

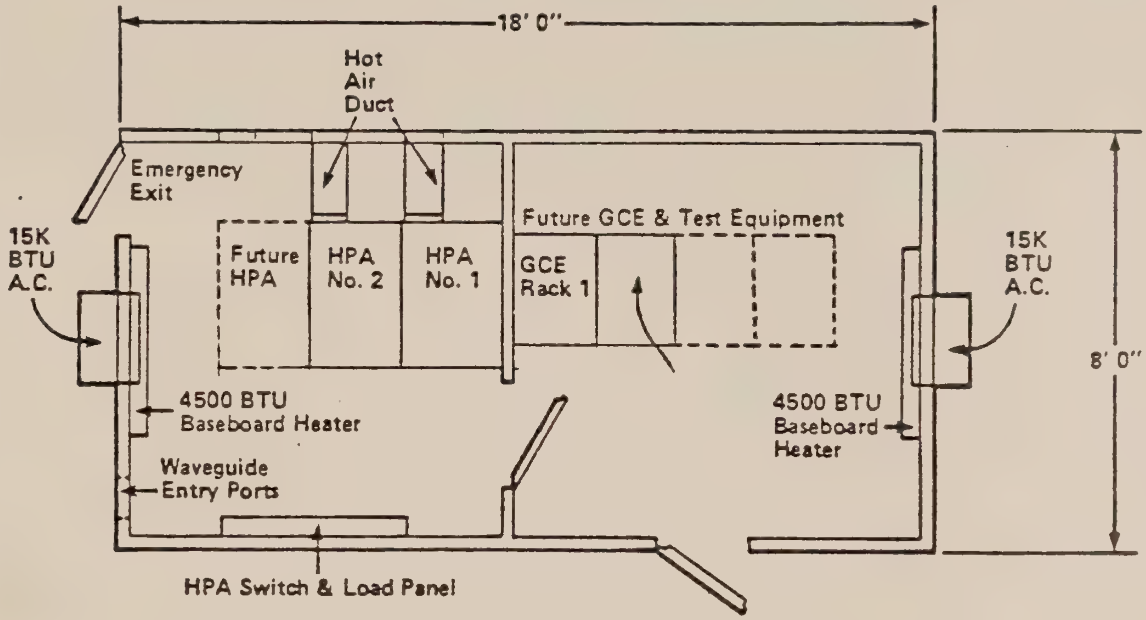



Figure 5. Electronics Equipment Shelter Floor Plan

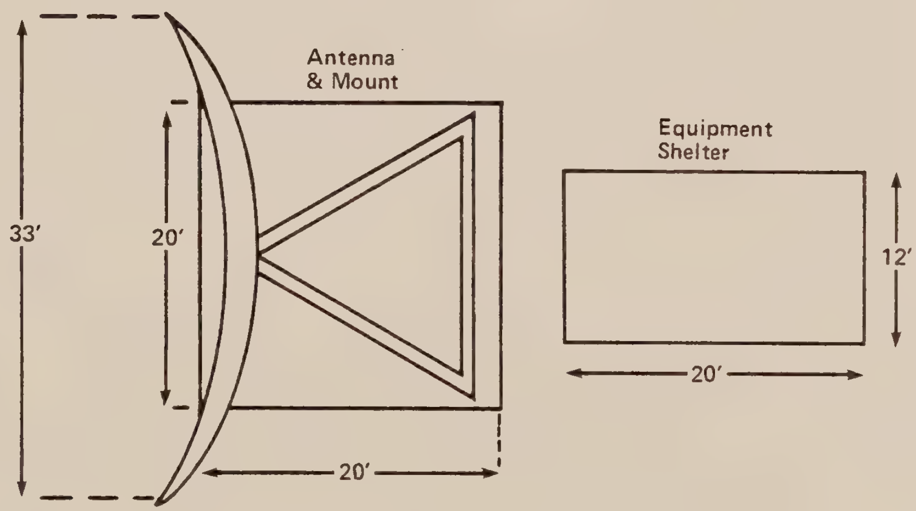



Figure 6. Typical Message/Video T/R Earth Station Layout

Figure 6 shows the site layout for large T/R earth station. A typical shelter layout is shown in Figure 7. Large mounts of work room and desk space are provided. Expansion may take place freely.

The antenna should be located such that no objects (trees, buildings, etc.) are positioned in the look angle of the antenna. If the RF path to the satellite arc is not clear, signals will be reduced and cross-polarization alignment may be effected.

The area which must be clear in front of the antenna extends to approximately 150 feet from the front of the main reflector. A cylinder of diameter 33 feet extended this distance may be visualized. This area must be clear.

Actual antenna height above the surrounding area is not a factor in site selection. The reduction in RF path gained by locating the antenna on a mountain is small compared to the total path length. In fact, locating the antenna in a low area will probably prove to be a blessing for frequency coordination.

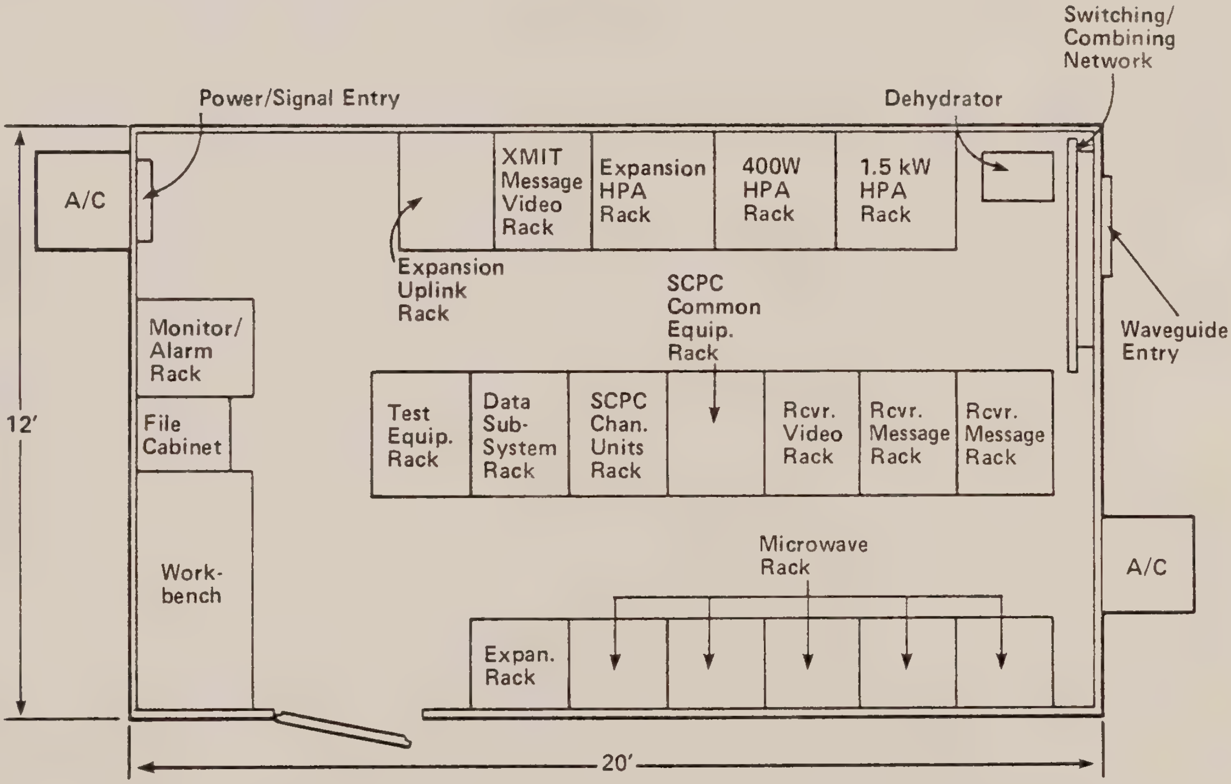



Figure 7. Typical Shelter Equipment Layout

If it becomes necessary to operate with more than one satellite simultaneously, two antennas will be necessary. Spacing between the antennas should be about 75 feet to ensure that one antenna does not look directly into the other. If the antennas were always looking away from each other, less spacing could be used. The equipment shelter should be located approximately between the antennas to provide as short a waveguide run as possible. A typical layout is shown in Figure 8.

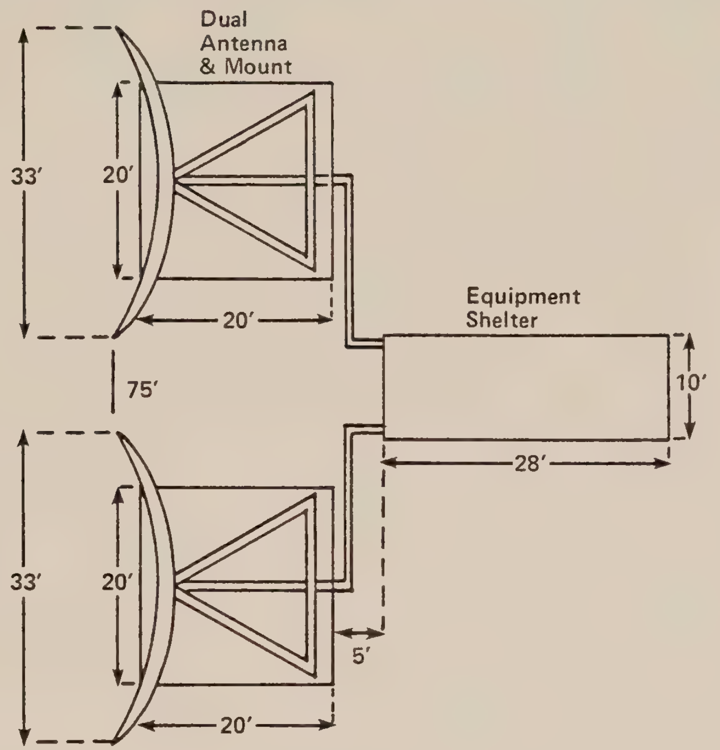



Figure 8. Typical Dual Antenna T/R Earth Station Layout

# EARTH STATION ANTENNA INTRODUCTION

James H. Cook
Principal Engineer

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Introduction**

Many components go together to form an earth station antenna system. All of these components have an individual role to play and their importance in the system should not be minimized. The antenna, of course, is one of the more important component parts of the system. In a receive-only application, the antenna receives the desired 4 GHz signals transmitted from the satellite and must provide sufficient discrimination to unwanted signals which occupy the same frequency bands. These signals may be from terrestrial microwave sources or other satellites. In a transmit and receive broadcast application the antenna not only receives signals as described above but also must transmit signals in the 6 GHz frequency band. In this case the antenna must discriminate from being interfered with and must have a sidelobe performance that prevents the transmitted signals from interfereing with adjacent satellites and existing terrestrial microwave systems operating in the 6 GHz frequency band.

**General Requirements**

Earth station antennas operating in the United States must meet the minimum requirements set forth in the FCC regulations pertaining to sidelobes. (See Part 25, Paragraph 25.209 of FCC Regulations and RM-2725, Amendment of the Commission's Rules and Regulations or Policies Relative to Satellite Earth Station Antennas to Permit Receive-Only "Small Earth Stations". Both of these documents specify a sidelobe envelope of:

$$(32 - 25 \log \theta) \text{ dBi} \qquad 1^\circ \leqslant \theta \leqslant 48^\circ$$
$$-10 \text{ dBi} \qquad 48^\circ \leqslant \theta \leqslant 180^\circ$$

where $\theta$ is the angle in degrees from the axis of the main lobe, and dBi refers to dB relative to an isotropic radiator. For the purposes of this envelope, the peak gain of an individual sidelobe may be reduced by averaging its peak level with the peaks of the nearest sidelobes on either side, or with the peaks of two nearest sidelobes on either side, provided that the level of no individual sidelobe exceeds the gain envelope by more than 6 dB. The antenna sidelobe envelope must conform to this specification in the 6 GHz transmit band and it is recommended that the antenna meet the envelope in the receive band. In the small antenna ruling, the Commission states that, "it appears that the carrier-to-interference objective will be satisfied for present domestic satellites if the earth station sidelobe levels do not exceed the envelope defined in Section 25.209 of the Rules and Regulations". (See Figure 1)

Earth station antennas operating outside the United States or antennas involved in international satellite communications should have sidelobe performance as specified by INTELSAT Standards or by CCIR Recommendation 483 and Report 391-2 (See Figure 2). The INTELSAT Standard is more stringent than the FCC document. The CCIR Standard is somewhat more lenient than the FCC document. Nevertheless, it should be pointed out that all three documents refer to the $(32 - 25 \log \theta)$ dBi envelope.

Another specification imposed on an earth station antenna is the G/T expressed in dB/(degrees K). This is a figure of merit which can be used to calculate overall system performance parameters such as C/N, S/N, etc.

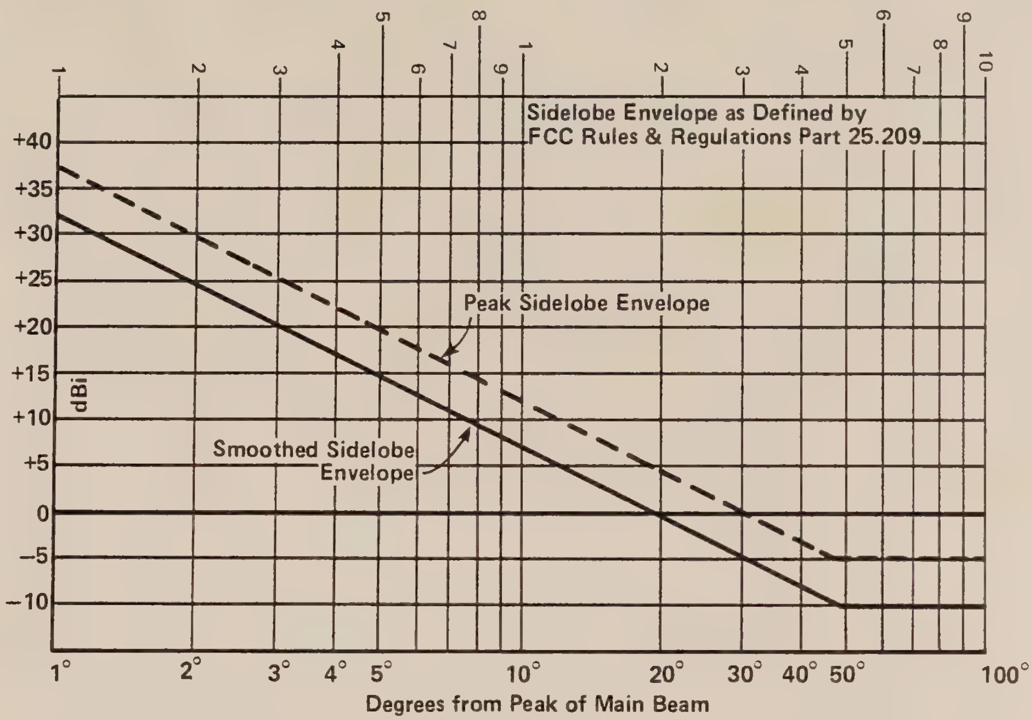



Figure 1

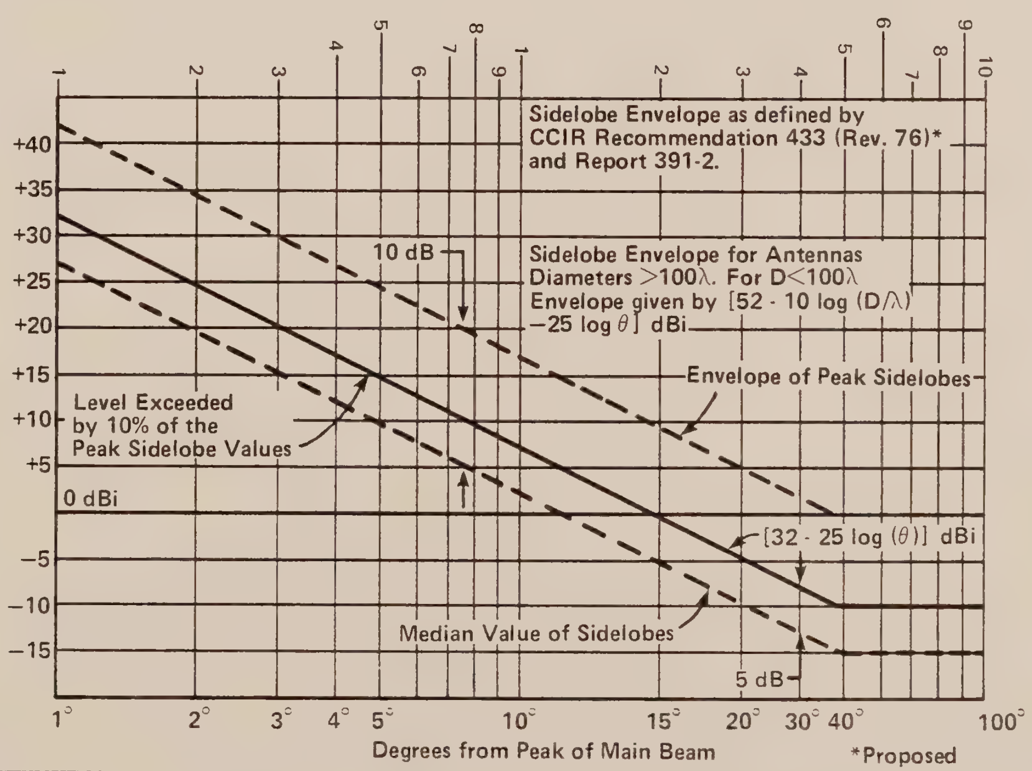



Figure 2

**Types of Earth Station Antennas**

Several types of earth station antennas are now in use within the United States and abroad. The majority of these are parabolic reflectors with focal point feeds, Cassegrain, and Gregorian dual reflector configurations with either special shaped main and sub-reflector or a parabolic main reflector and conventional hyperbolic or ellipsoidal subreflector or special shaped subreflector. Other types consist of horn reflectors, offset fed reflectors, and Torus antennas.

Cassegrain antennas are one of the most common. They can be divided into three primary types:

1. The classical Cassegrain geometry [1, 2] employing a parabolic contour for the main reflector and a hyperbolic contour for the subreflector (see Figure 3). The parabolic reflector is a point focus device with a diameter of $D_p$ and a focal length of $f_p$. The hyperbolic subreflector has two foci. For proper operation one of the two foci is the real focal point of the system, and is located coincident with the phase center of the feed; and the other foci, the virtual focal point, is located coincident with the focal point of the parabolic main reflector.
2. A geometry consisting of a parabolic main reflector and a special shaped, quasi-hyperbolic subreflector[3]. The geometry in Figure 3 is appropriate for describing this antenna. The main difference between the classical Cassegrain mentioned above is that the subreflector has been designed such that the overall efficiency of the antenna has been enhanced thereby yielding improved gain performance. This technique is especially useful with antenna diameters of approximately 30 to 100 wavelengths; i.e., 5 meter antenna in the 4 and 6 GHz frequency bands.
3. A generalization of the Cassegrain geometry consisting of a special shaped quasi-parabolic main reflector and a shaped, quasi-hyperbolic subreflector [4, 5, 6]. By use of geometrical optics the reflector shapes can be determined which allow the arbitrary selection of a phase and amplitude distribution over the main reflector aperture when given a particular feed distribution on the subreflector. This type of Cassegrain antenna is generally used when maximum gain is needed for a given size reflector antenna.

The other type of antenna most often employed in the United States for a receive-only application is the prime focus fed parabolic antenna. This type of antenna has excellent sidelobe performance in all areas except the spillover region around the rear edge of the reflector. Even in this area the antenna satisfies the FCC pattern requirements. The antenna efficiency is in the 60% region and therefore is a good compromise choice between sidelobes and gain. Over 125 of these antennas have been installed in the United States.

Two other types, in particular, have been or are being considered for use as an earth station antenna. These are horn reflectors and offset fed parabolic reflectors. The horn reflector antennas can be grouped into two types:

1. The pyramidal horn reflector has been used for many years in the terrestrial microwave business, primarily by A.T.T. This antenna offers reasonably good efficiency and very good sidelobe performance especially in the near in region and in the back region. Its performance is a result of its closed configuration and lack of blockage that is inherent in the antenna types mentioned above. Diffraction energy around the radiating aperture does produce a significant region of energy about 90° off axis. Cross-polarization response off axis is another area of concern, especially when used with a frequency reuse satellite.

2. The conical horn reflector is similar in design to the rectangular horn reflector mentioned above. It has similar advantages and disadvantages with some exceptions. The first sidelobe is improved due to the circular aperture. The conical horn also has less wind resistance than the pyramidal horn again resulting from its basic shape.

Both the pyramidal and conical horn reflector have lower noise temperatures than dual reflector and point focus reflector antennas. Both also have unique mounting requirements which are somewhat restrictive and cumbersome. The overall length of the antenna, for example, is typically twice the aperture size. Problems with transportation can also occur due to the large physical dimensions of the antenna.

To date the offset fed parabolic has not been used as an earth station antenna in the United States to my knowledge. This probably will not be the case in the near future. The offset fed parabolic (see Figure 5) minimizes the diffraction scattering by eliminating the aperture blockages of the feed and feed support structure. The spillover energy around the periphery of the reflector is still present therefore a high level of back radiated energy will exist for some small finite region. Sidelobe levels of (32 - 30 log $\theta$) dBi can be expected from this type of antenna with the exception of the spillover region. Aperture efficiencies of 55 - 60% can be expected. This antenna type may present some unusual and interesting mount configurations. For a more detailed discussion of this antenna, see C. Mentzer[7]. Offset fed dual reflectors exhibit similar sidelobe advantages and can be shaped for aperture efficiencies in the 70 - 75% range and are a definite candidate for future applications.

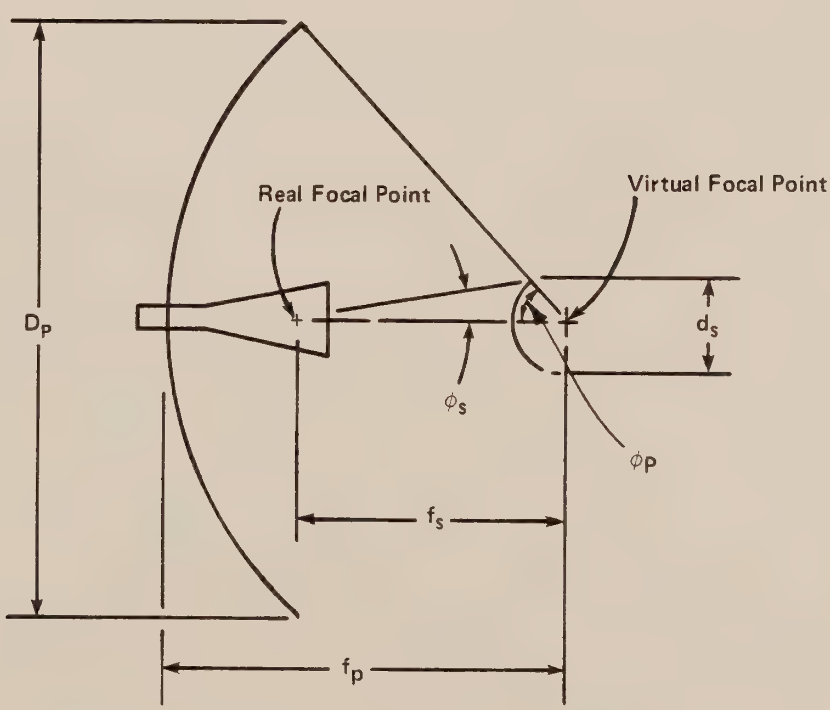



Figure 3. Geometry of the Cassegrain Antenna System.

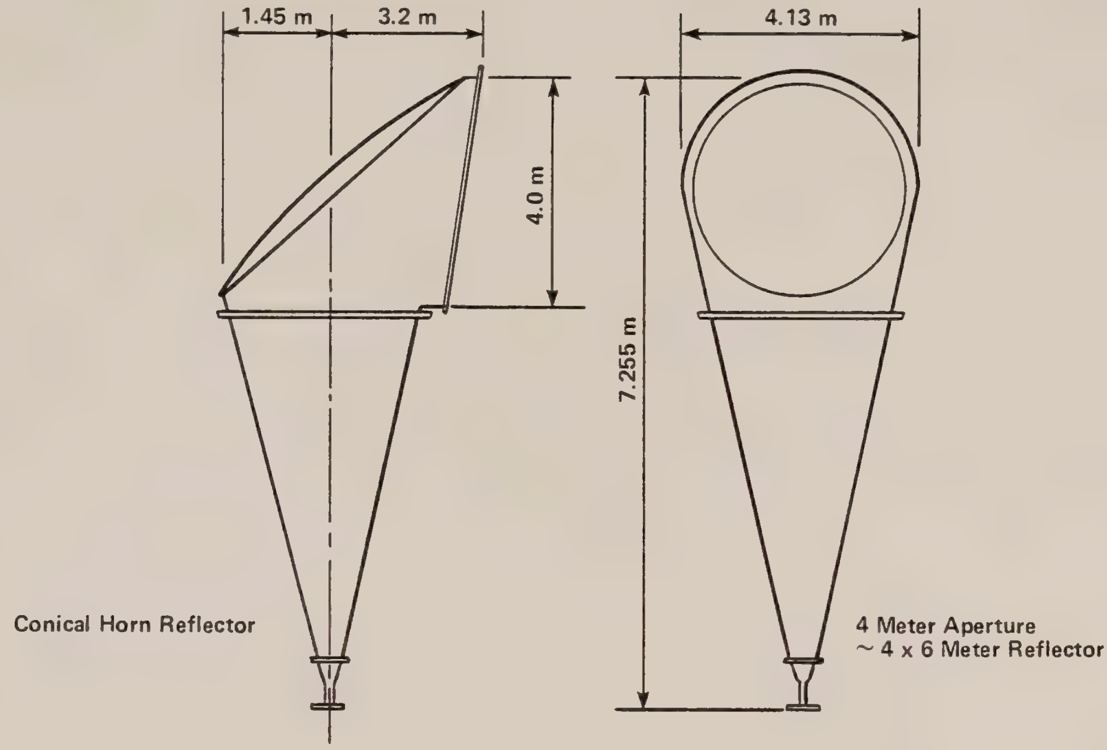



Figure 4. 4 Meter Conical Horn Reflector Antenna

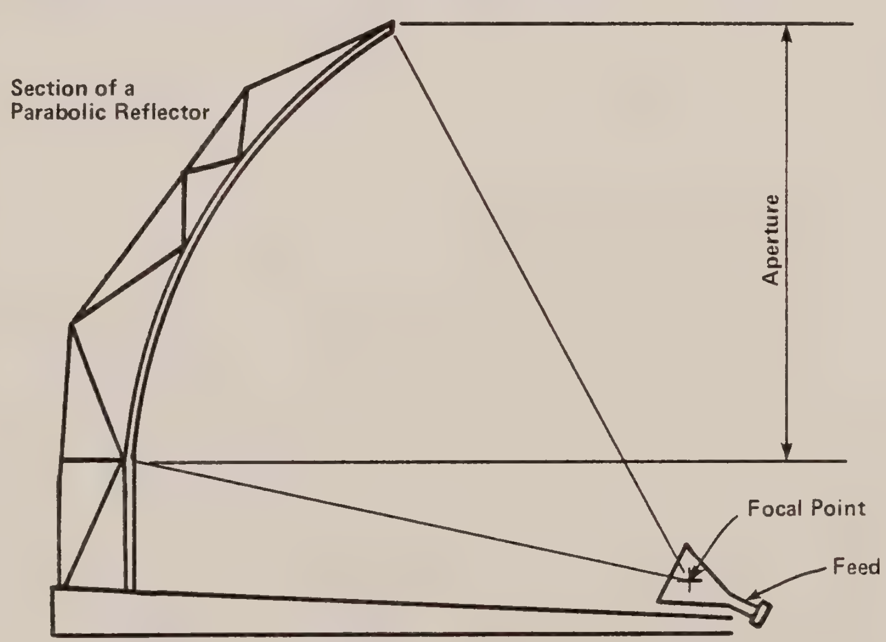



Figure 5. Basic Offset Fed Parabolic Antenna

**Performance of an Earth Station Antenna**

The performance of an earth station antenna can be expressed in three primary specifications: gain, sidelobes, and noise temperature. The gain achievable is largely a function of the uniformity of the illumination of the antenna aperture and the accuracy of the reflector surface. The gain is related to the directivity of the aperture by an efficiency factor. The maximum, theoretical directivity of an aperture can be obtained by:

$$\text{Dir} = \frac{4\pi A}{\lambda^2} \tag{2}$$

where A is the aperture area
$\lambda$ is the wavelength

For a circular aperture this equation reduces to:

$$\text{Dir} = \left(\frac{\pi d}{\lambda}\right)^2 \tag{3}$$

Expressing equation (3) in decibels relativeto an isotropic radiator can be approximated by:

$$\text{Dir.} \approx 20 \log (10.5\ f\ d) \tag{4}$$

where f = frequency in GHz
d = diameter in meters

Gain then can be found by:

$$G \approx 20 \log (10.5\ f\ d) - 10 \log (\eta) \tag{5}$$

where $\eta$ is the efficiency factor

The sidelobe and back lobes of an antenna depend primarily on the amount of energy which spills over the edges of the primary and secondary reflectors, the primary feed pattern and the amount of energy obstructed by and reflected by the various parts of the structure such as spar supports, subreflector, and feed housing.

The noise temperature of the antenna is made up of contributions of the main beam, sidelobes, and backlobes. A detailed analysis of the antenna noise temperature is contained within the seminar notes.

G/T is a figure of merit of an earth station antenna system which is widely used in earth station engineering. The importance of this factor becomes quite obvious when system performance is discussed. For instance the system video signal-to-noise ratio is a direct function of G/T. G/T is defined as the ratio of the receive system gain at a specified reference point to the total receive system noise temperature. The gain and noise temperature must be referenced at the same point. The units of G/T are almost always referred to as dB/ °K even though this is somewhat misleading. The figure of merit is:

$$G/T = 10 \log (g/t_s)$$
$$= 10 \log (g) - 10 \log (T_s) \tag{6}$$

Now 10 log (g) is the gain of the antenna in decibels above an isotropic radiator and $T_s$ is the total noise temperature of the receiving system in degrees Kelvin.

An example may be useful in explaining this figure of merit.

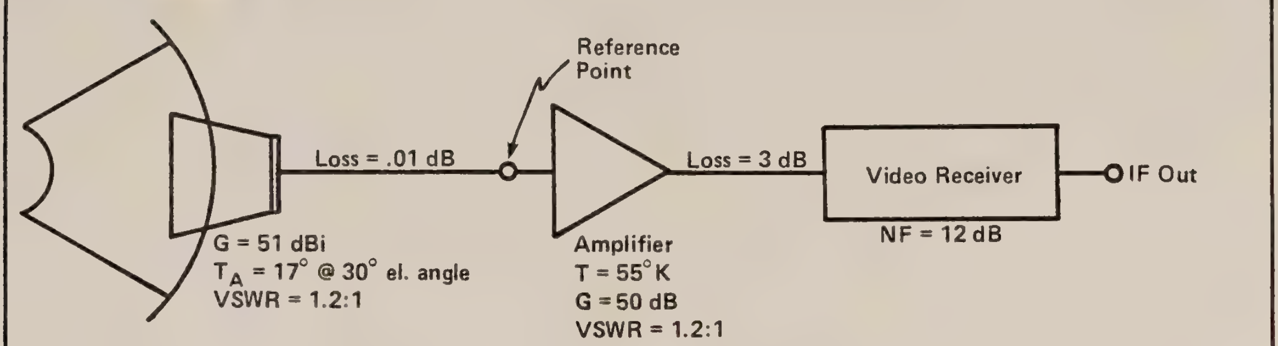



Figure 6

The gain at the reference point is:

$$G_R = G_A - L_1 - \text{mismatch loss} \tag{7}$$
$$= 51.00 - 0.01 - 0.14$$
$$= 50.85 \text{ dBi}$$

The 0.14 dB mismatch loss arises from the worst case combination between the two 1.2:1 VSWR's.

The system noise temperature may be calculated from the expression:

$$T_S = \frac{T_A}{L_1} + \left(\frac{L_1 - 1}{L_1}\right) T_o + T_{amp} + \frac{1}{G_{amp}} \left\{ (L_2 - 1)\, T_o + L_2\, (NF - 1)\, T_o \right\}$$

where
$T_A$ = antenna noise temperature
$L_1$ = loss between antenna and reference point
$T_{amp}$ = amplifier noise temperature
$G_{amp}$ = amplifier gain
$L_2$ = loss between reference point and receiver
NF = noise figure of receiver (power ratio)

An important fact to remember is that none of the units in equation (8) are in dB, but are power ratios or degrees.

For example:

$T_A = 17°K$ NF = 15.849
$L_1 = 1.0023$ $T_o = 290°K$
$G_{amp} = 10^5$ $T_{amp} = 55°K$
$L_2 = 2.0$

$$T_s = \frac{17}{1.0023} + \left(\frac{1.0023 - 1}{1.0023}\right) 290 + 55 + \frac{290}{10^5} \left[ (2 - 1) + 2\,(15.84 - 1) \right]$$

$$T_s = 16.96 + .665 + 55 + \text{negligible}$$

$$T_s = 72.626°K$$

$$G/T = 50.85 - 10 \log T_s$$

$$G/T = 32.24 \text{ dB}/°K$$

Another useful point to remember concerning G/T is that it is not dependent upon the reference point. No matter where one chooses the reference point the G/T remains constant.

An application of G/T is the calculation of the carrier-to-noise ratio:

$$C/N = EIRP - L_p + G/T - K - B_{IF}$$

where EIRP = effective isotropic radiated power dBW
$L_p$ = path loss in dB
G/T = dB/ °K
K = −168.6 dBW/MHz 1° K
$B_{IF}$ = 10 log $b_{if}$ where $b_{if}$ is the effective noise bandwidth of the receiver IF in MHz.

Since C/N is a direct ratio of G/T, a 1 dB change in G/T results in a 1 dB change in C/N.

**Summary** Many kinds of antennas are used as earth station antennas. For overall performance prime focus fed parabolic and the dual reflector, Cassegrain antennas have been the predominant types of antennas used. Their choice has been based on sound engineering judgment for the best tradeoffs between electrical and mechanical performance commensurate with cost. It is expected that these types of antennas will continue to be the earth station antenna for many years to come.

**References**

1. P.W. Hannah, "Microwave Antennas Derived from the Cassegrain Telescope" IRE Transactions on Antennas and Propagation, March 1961, pp 140-153.
2. P.A. Jensen, "Designing Cassegrain Antennas", Microwaves, December 1962, pp 10-16.
3. G.W. Collins, "Shaping of Subreflectors in Cassegrainian Antennas for Maximum Aperture Efficiency", IEEE Transactions on Antennas and Propagation, Vol. AP-21, No. 3, May 1973, pp 309-313.
4. V. Galindo, "Design of Dual Reflector Antenna with Arbitrary Phase and Amplitude Distributions", PTGAP Int. Symp., Boulder, Colo., July 1963.
5. V. Galendo, "Synthesis of Dual Reflector Antennas", Elec. Research Lab., Univ. of Calif., Rept. No. 64-22, July 30 1964.
6. W.F. Williams, "High Efficiency Atnenna Reflector", Microwave Journal, July 1965, pp 79-82.
7. C.A. Mentzer, "Analysis and Design of High Beam Efficiency Aperture Antennas", Doctoral Thesis 74-24, 370, Ohio State Univ., 1974.

# GROUND STATION ANTENNAS FOR SATELLITE COMMUNICATIONS

Marvin Shoemake
Product Line Manager
Satellite Communications Antenna Products
and
Robert J. White
Senior Antenna Engineer
Electro-Products Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

# GROUND STATION ANTENNAS FOR SATELLITE COMMUNICATIONS

## I. Introduction

*The earth station antenna is a vital link between the satellite and ground station equipment. It must provide a reliable high gain receiving element under sometimes severe environmental conditions. In addition the far field pattern of this antenna must have sufficiently low wide angle sidelobes to suppress interfering signals within the very congested operating bands. It is the intent of this paper to outline the antenna requirements, and provide a cursory look at the reflector type antenna usually used to meet these requirements.*

## II. Earth Station Antenna Requirements

*Earth station antenna requirements are dependent on many factors such as channel capacity, receiving equipment, signal modulation, reliability requirements, geographical location relative to the satellite, site interference profiles and site environmental conditions to name a few. This discussion will be limited to the requirements for small earth terminals with one or two video downlink channels and possibly a single uplink channel.*

*As mentioned previously, antenna requirements are to some extent site related and because of this the following table may not be applicable for all sites. It does, however, outline typical requirements for an average continental U.S. site.*

*These antenna requirements are given as flexible guidelines which may vary with total system performance requirements.*

| Characteristic | Specification |
|---|---|
| Frequency of Operation | 3700-4200 MHz Receive<br>5925-6425 MHz Transmit |
| Receive System G/T | 24 dB/ °K minimum (see Figure 1) |
| Transmit System EIRP | ≈82 dBw for satellite saturation (see Figure 2) |
| Beamwidth | Consistent with gain requirements |
| First Sidelobe | 14 dB maximum |
| VSWR | 1.25:1 Receive band<br>1.25:1 Transmit band |
| Polarization Discrimination | -30 dB (relative to peak of co-polarized beam) |
| Maximum Transmit Power | 5 kW average<br>10 kW peak |
| Pressure | 2 psig nominal |
| Polarization Rotation | ± 90 ° |
| Isolation (transmit to receive) | 30 dB |
| Pattern Envelope | Compliant with FCC Regulation 25.209 |

Table 1. Earth Terminal Antenna Requirements.

## III. Antenna Types and Design Considerations

*The antenna characteristics given in Table 1 are applicable primarily to reflector type antennas 5 - 11 meters in diameter. The reflector antenna is the most widely used and accepted type of antenna primarily because it fits the system antenna requirements, but it is also desirable from a construction simplicity, economic and availability standpoint. Figures 3, 4, 5 and 6 show some of the earth station antennas manufactured by Scientific-Atlanta in the 5 - 11 meter size category.*

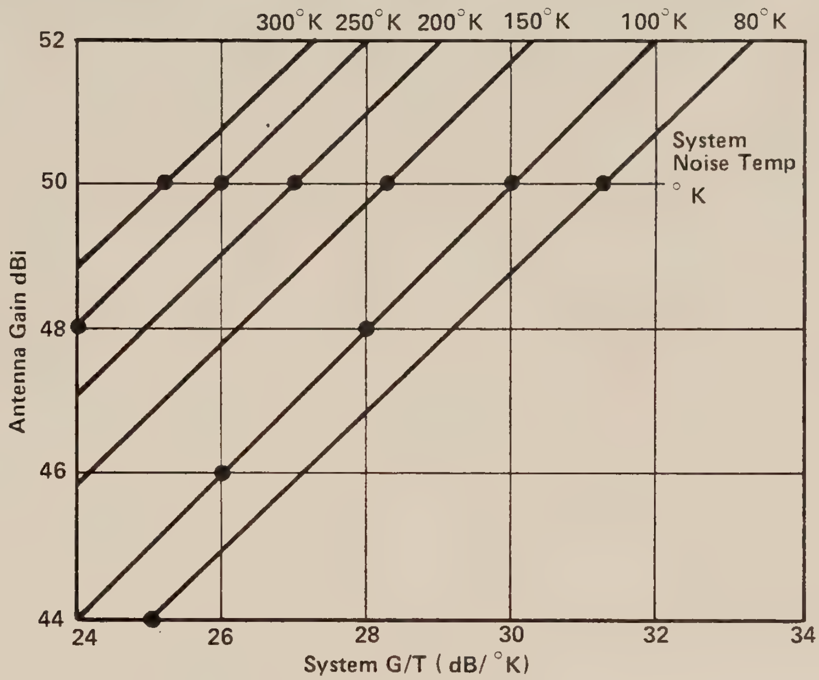



Figure 1. System G/T vs. Antenna Gain

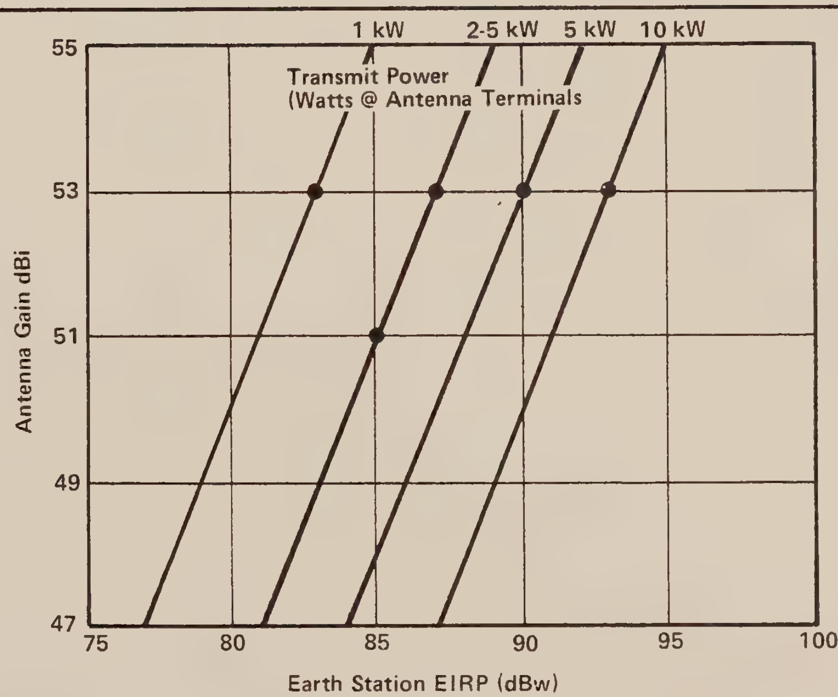



Figure 2. Earth Station EIRP vs Antenna Gain

Figure 3. 5 Meter Earth Station

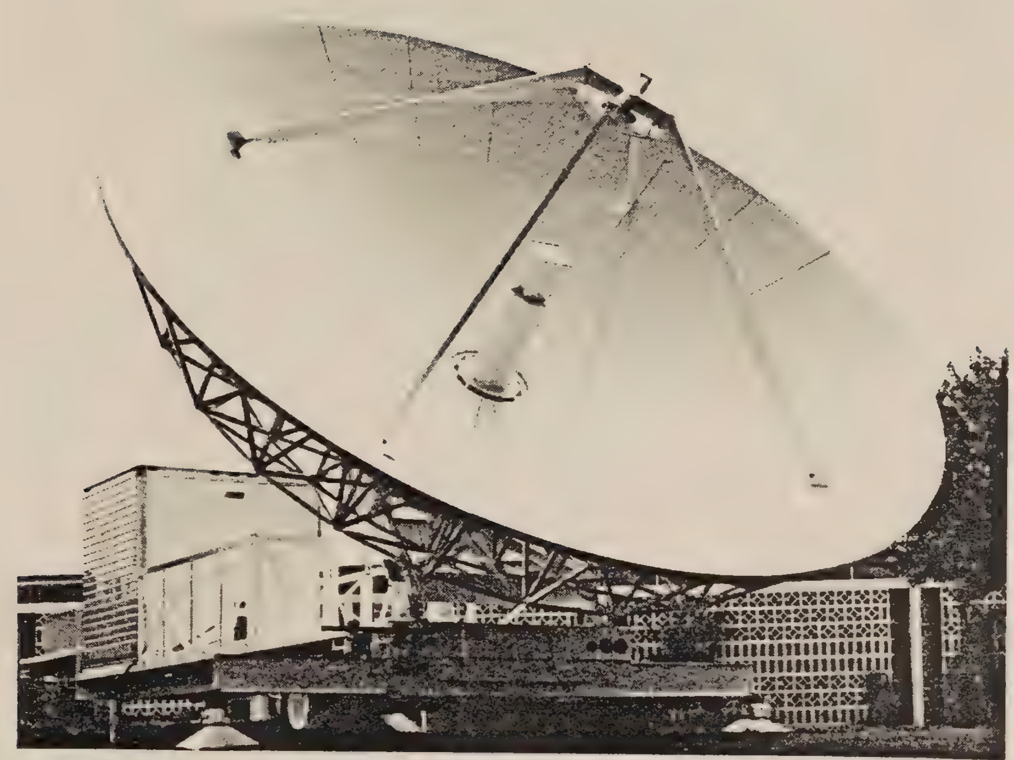


Figure 4. 8 Meter Transportable Earth Station

Figure 5. 11 Meter INTELSAT B Earth Station

Figure 6. Dual Reflector 10 Meter Alaskan Earth Station

*A parabolic or near parabolic reflector is shown graphically in Figure 7. It is a surface of revolution which has an associated focal point or focal region in the case of a shaped paraboloid. The position of this focal point is determined by the shape of the surface which also describes a subtended angle between the focal point and the edge of the reflector. The distance from the reflector vertex to the focal point is referred to as the focal length.*

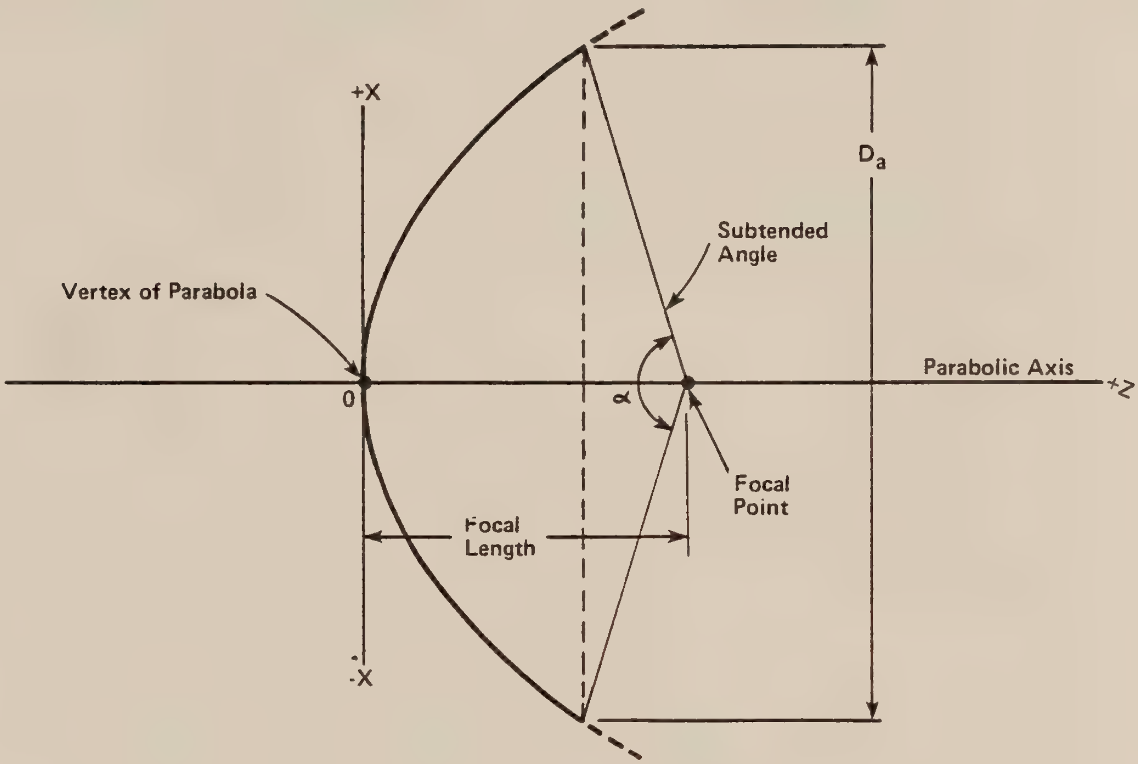



Figure 7. Geometry of Parabolic Reflector.

*Most of the energy captured by the reflector is focused to the focal point where it is received by an antenna element or a feed. The feed for this prime focus geometry is connected to the receive system through some form of transmission line. Another approach to receiving this focused energy is to place a subreflector at the focal point which focuses the signal it receives into a feed located at or near the vertex of the main reflector. This is commonly referred to as a Cassegrainian or dual reflector type of antenna.*

*The basic requirements for the efficient operation of any reflector antenna are proper amplitude illumination and equal phase paths across a relatively unobstructed reflector aperture. However, the problems associated with optimizing these factors are sometimes complex and require much analytical and empirical analysis. Some of the considerations applicable to achieving an optimum design are presented in the following sections.*

**Prime Focus Antenna Geometry**

*The feed of the prime focus configuration, shown graphically in Figure 8 is key to the resultant secondary antenna characteristics such as gain beamwidths, sidelobes, wide angle radiation, and even noise temperature. Specifically it is the feed primary pattern which weighs most heavily in*

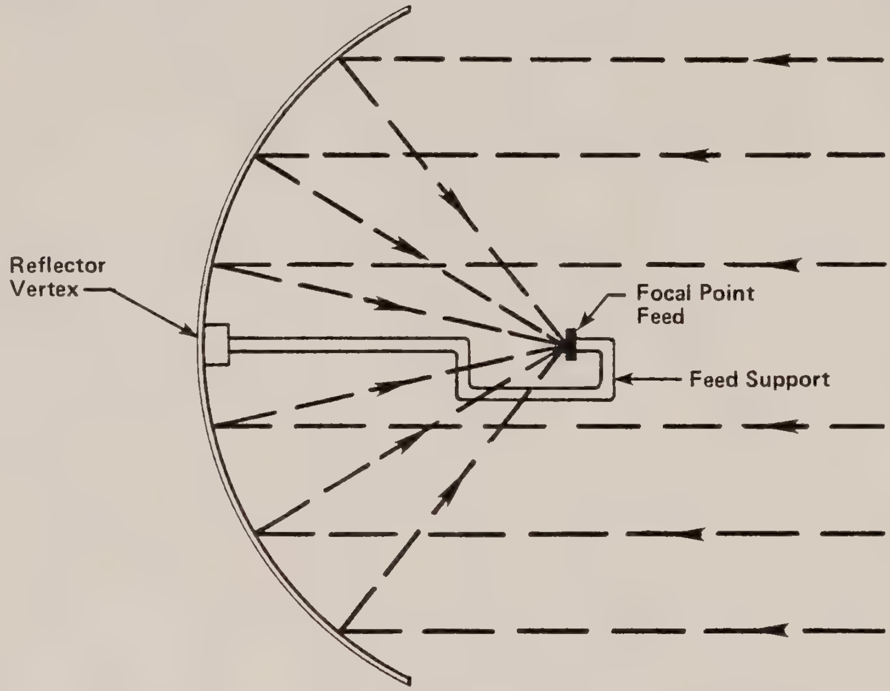



Figure 8. Geometry of Prime Focus Feed Reflector Configuration.

*determining these characteristics. If an ideal feed pattern as shown in Figure 9 could be achieved then it would be possible to achieve almost 100 percent usefulness from the total physical area. This pattern would uniformly illuminate a reflector with a subtended angle of 140° then drop to zero at that angle ideally capturing all the RF energy in the field impinging on the reflector aperture. Of course this also assumes ideal conditions for other contributing factors such as feed phase taper, reflector surface tolerance and aperture blockage.*

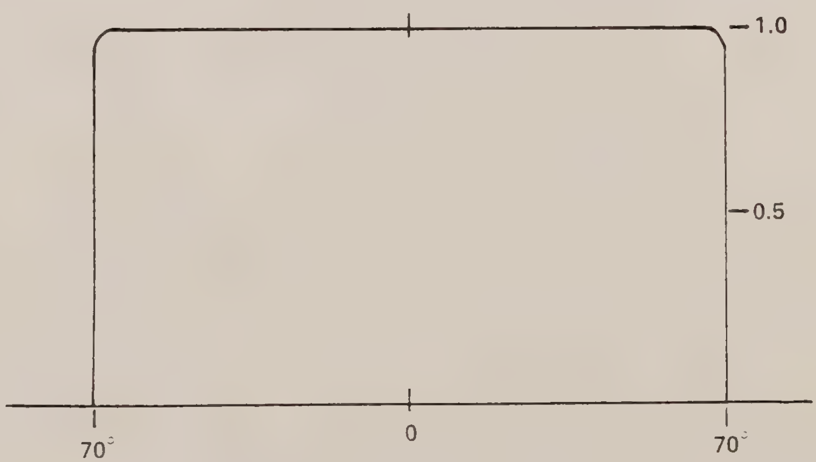



Figure 9. Ideal Feed Pattern.

*A feed pattern of the type shown in Figure 9 is not achievable. However, there are feeds of the corrugated and multimode horn types which are capable of approaching this ideal pattern as shown in Figure 10. This typical pattern is from a corrugated horn presently used as the feed for a 10-meter earth station antenna. One can achieve illumination efficiencies on the reflector as high as 80 percent with a circular symmetric pattern of this type.*

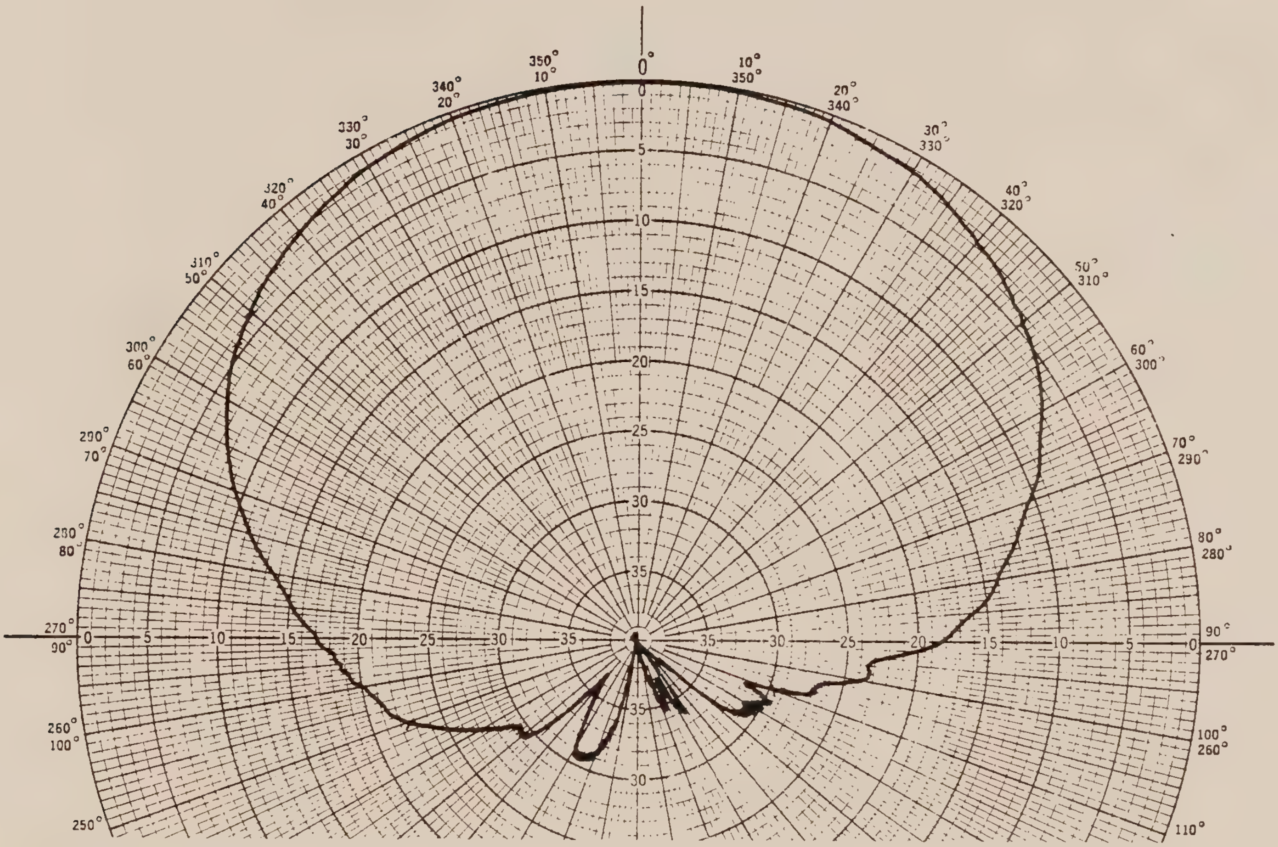



**Figure 10. Typical Feed Pattern of Prime Focus Corrugated Horn.**

*Figure 11 shows the two patterns of Figures 9 and 10 superimposed. The shaded areas are the two areas of concern which degrade antenna efficiency. The upper shaded area denotes the departure from a uniform taper or illumination out to the reflector half angle. This particular pattern, because of it's 10 dB taper, has the effect of reducing the illumination efficiency from 100 to 80 percent. The lower shaded area is the feed radiation which is spilled over the edge of the reflector. The term used to describe its effect to total antenna efficiency is, appropriately enough, spillover efficiency. This typical feed pattern has a spillover efficiency of 90 percent. Also the phase taper and cross polarization efficiencies are in the 97 percent range. The resultant of these efficiencies yields a feed illumination of approximately 74 percent. The gain of the antenna is reduced still further by random phase errors due to reflector surface tolerances and blocked aperture area by the feed and its support. These two effects reduce the total antenna efficiency to 64 percent at the feed aperture. This means that 64 percent of the power density within a uniform field at the reflector aperture would be captured by the feed. This relatively high efficiency from a prime focus antenna can only be achieved by employing design techniques which include, utilizing a feed with primary pattern characteristics similar to the pattern shown in Figure 10, minimizing the blockage area from the feed and its support structure to less than 2 percent of the total reflector area and maintaining the reflector rms surface tolerance shape to within λ/10 of a true paraboloid.*

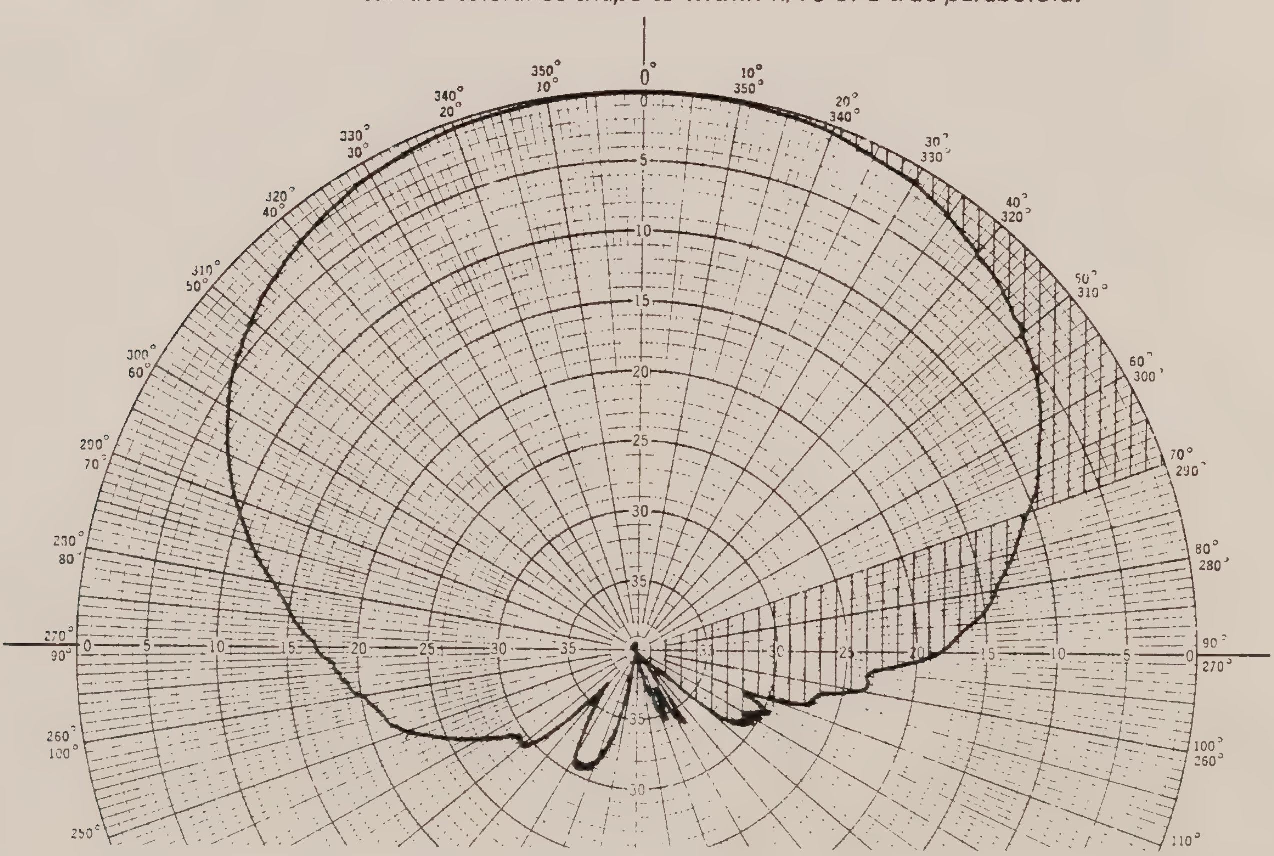


Figure 11. Actual Feed Pattern to Ideal Feed Pattern Comparison.

*The far field pattern of a reflector is of course a diffraction pattern whose characteristics are controlled primarily by reflector size, frequency of operation, feed amplitude and phase pattern, reflector surface perturbations, blocked reflector area, and the diffraction contributors within the antenna geometry. These pattern characteristics are of significant importance to an operating earth station because of extreme congestion in the 4/6 GHz operating bands. The spectrum congestion from terrestrial microwave systems and its potential interference is probably the prime factor in locating an earth station antenna. In order to minimize the interference, an antenna which has been designed for wide angle pattern suppression is desirable. The pattern exhibited by the antenna could be the determining factor in establishing a site location.*

*The patterns shown in Figures 12 and 13 are typical patterns of a 10-meter prime focus antenna at 4 and 6 GHz. This antenna has been designed to minimize wide angle sidelobes. The pattern envelope of FCC regulation 25.209 is plotted as a comparison. This antenna pattern is achievable by placing the feed at the focal point of the main reflector to limit the spillover and edge diffraction contributions to one area of the pattern rather than two in the case of the dual reflector antenna. The pattern area affected in the prime focus configuration is in the 100 - 110° region of the pattern. Also the blockage area from the feed and its support is limited to less than 2 percent of total reflector area. This is important because any blocked area within a reflector has associated with it a broad low level pattern which has*

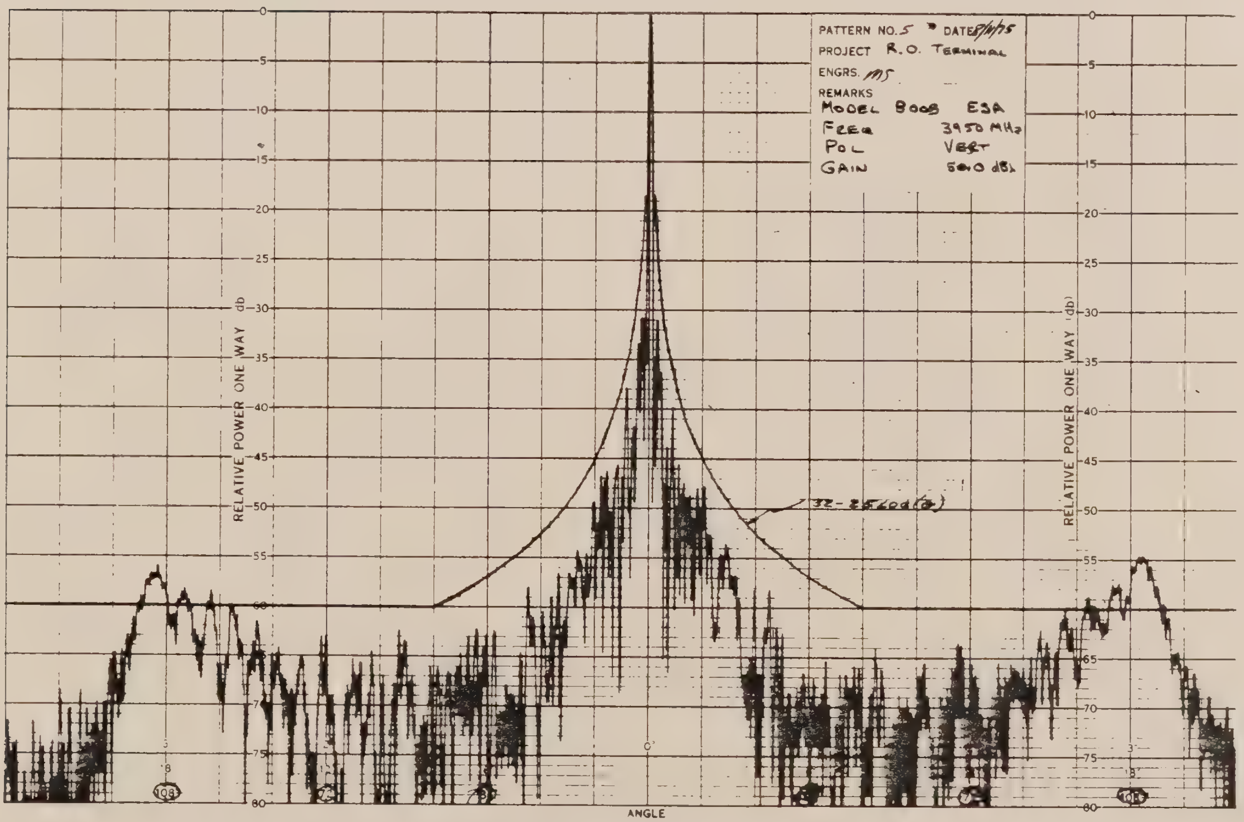



Figure 12. Typical 4 GHz Pattern of 10 Meter Prime Focus Antenna.

*the effect of broadening the resultant far field patterns. Obviously the larger the area blocked the broader the resultant pattern will be. Keeping the blockage to a minimum has another effect in that it also reduces the possibility of scattering or reradiation increasing the wide angle sidelobes.*

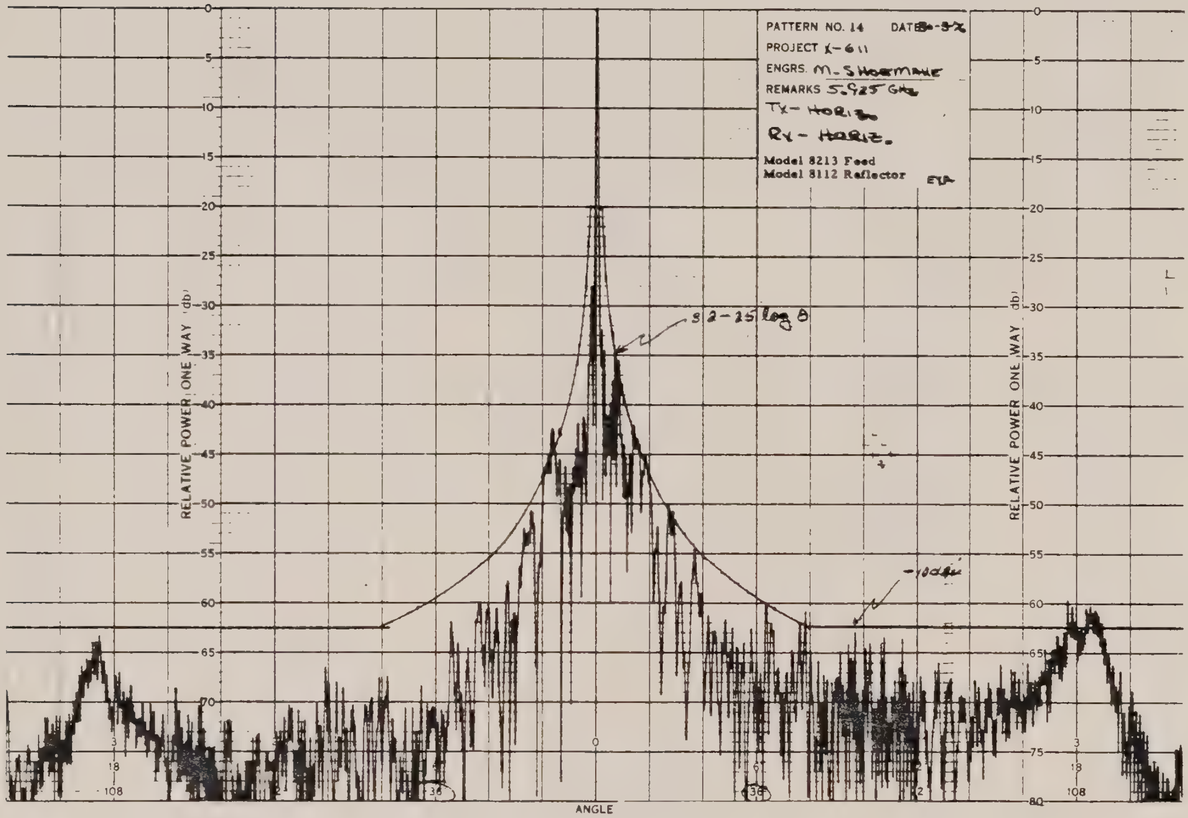



Figure 13. Typical 6 GHz Pattern of Prime Focus Antenna.

*The cross polarization far-field pattern of the earth station antenna is important to providing the high polarization discrimination characteristics required when operating with a spectrum reuse satellite. If the antenna is designed to achieve the characteristics previously described then the cross polarization pattern will be determined by the corresponding feed pattern. The excellent cross polarization characteristics of a corrugated horn are well known and therefore the cross polarization pattern of a 10 meter reflector shown in Figure 15 is achieved by utilizing this type of feed.*

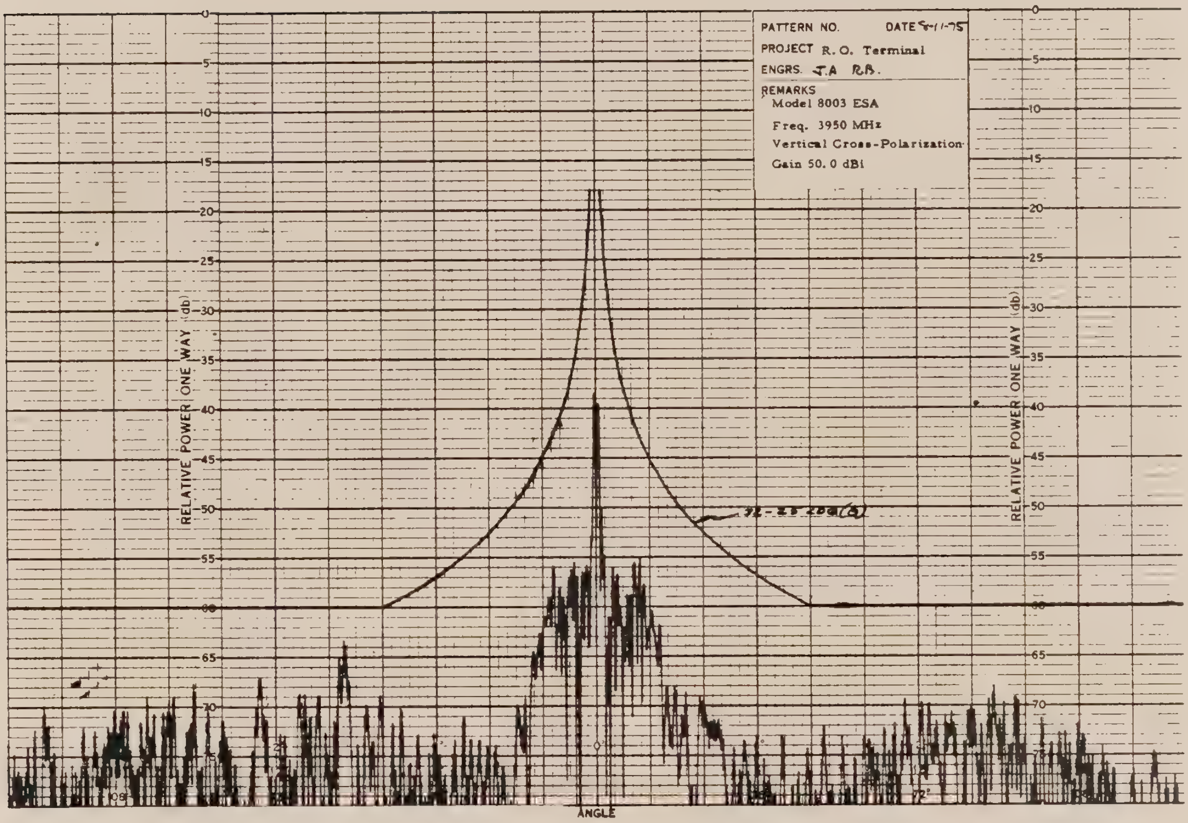



Figure 15. Typical Cross Polarization Pattern of 10 Meter Prime Focus Antenna.

**Cassegrain Antenna Geometry**

*The Cassegrain antenna design is derived from the telescope design of William Cassegrain. It is a dual reflector antenna employing what are normally termed a "main reflector" and a "subreflector". In the true Cassegrain geometry the main reflector is a paraboloid and the subreflector a hyperboloid. Variations include the Gregorian design with an ellipsoidal subreflector and so-called "shaped" designs where the surfaces are generated numerically without determining a closed form solution for them.*

*As shown in Figure 16 and 17, the Cassegrain feed horn/subreflector combination replaces the feed in the prime focus configuration. This leads to several advantages and several disadvantages as will be discussed. Presently, however, consider that a plane wave is impinging on the main reflector. Being paraboloidal, the main reflector directs all the rays toward its focal point just as in the prime focus geometry. Now, however, the hyperboloidal subreflector reflects the rays to its second focal point. The primary feed horn is placed so that its phase center is coincident with this second subreflector focus and therefore it receives the incoming energy. By reciprocity, the process can simply be reversed on transmission.*

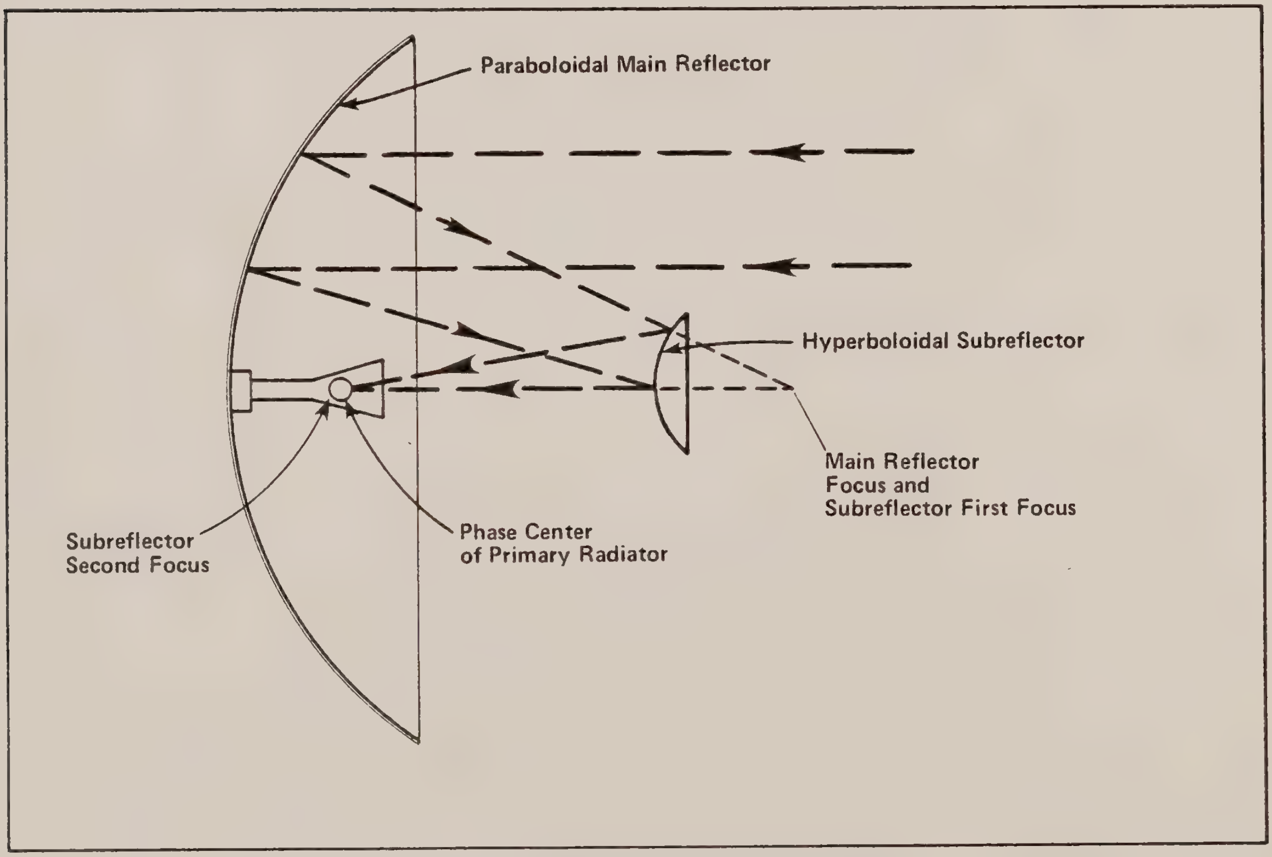



Figure 16. Cassegrain Antenna Geometry.

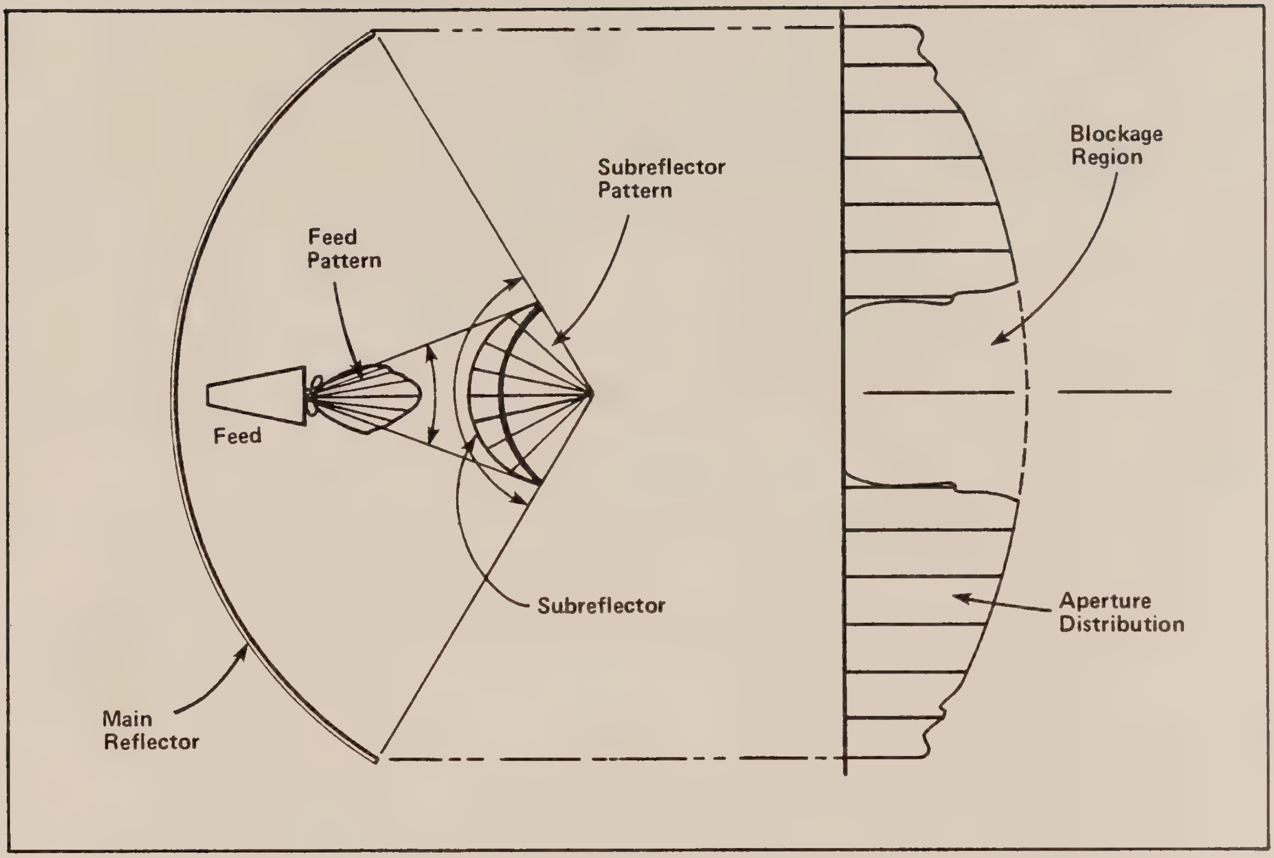



Figure 17. Aperture Distribution of a Cassegrain Antenna.

*This simplified discussion is based strictly on geometrical optics, realizable only by working with zero wavelength or infinite structures. In real antennas the performance is affected by diffraction effects, particularly from the subreflector edges. These effects alter the pattern produced by the subreflector as it illuminates the main reflector (considering the antenna as a transmitter). A typical scatter pattern is shown in Figure 18. This is the pattern formed by the feed/subreflector combination. Notice the ripple caused by energy diffracting at the subreflector edges.*

*The subreflector diffraction effects limit the use of dual reflector antennas to main reflectors of about 40 λ and larger, with the exact limit of course depending on specifications. A typical standard Cassegrain antenna of 80 λ in diameter will give 55–60% overall efficiency.*

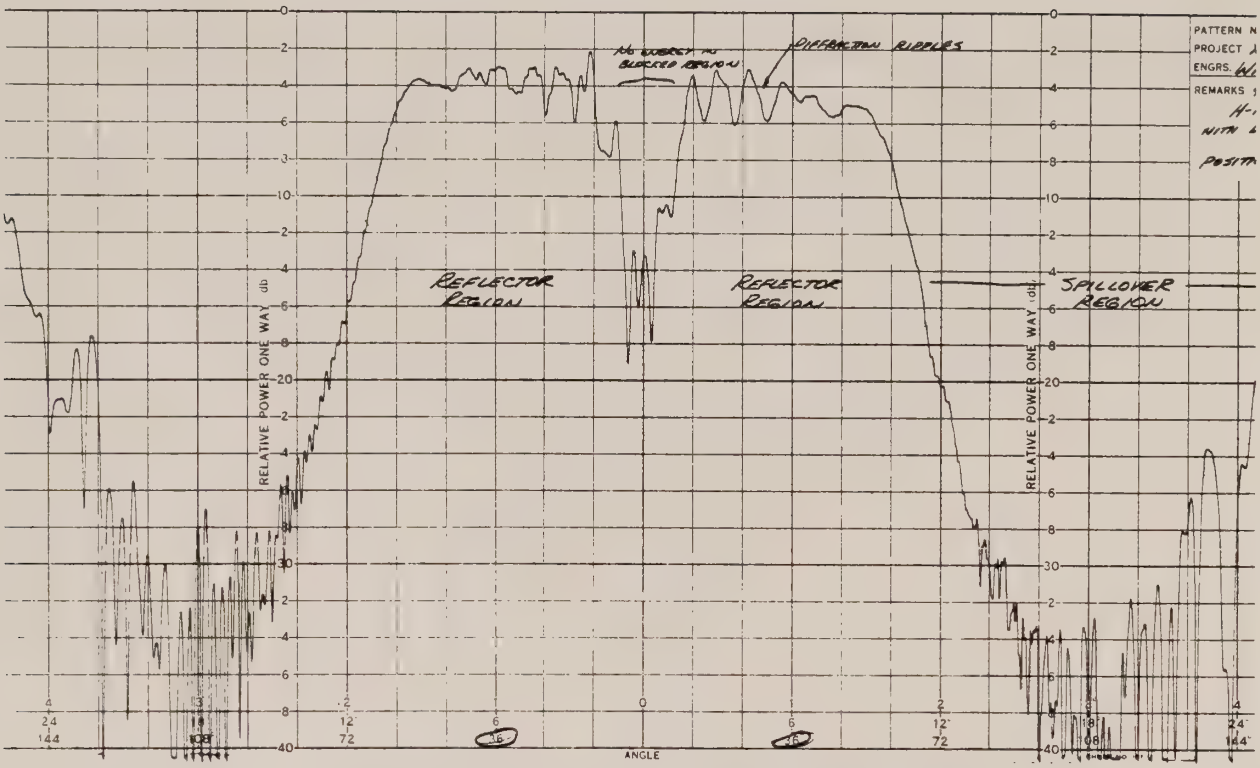



**Figure 18. Typical Feed/Subreflector Scatter Pattern.**

*As with all antennas the efficiency (therefore gain) of a Cassegrain system depends in part on the amplitude and phase distribution across the aperture, with the maximum theoretical gain being produced by both amplitude and phase being uniform. The Cassegrain design ensures uniform phase as can be seen by verifying that all rays travel equal distances from the feed to the subreflector to the main reflector and back to the antenna aperture plane.*

*After ensuring uniform phase we investigate the aperture amplitude distribution. This is straightforward if we think of the Cassegrain antenna in its equivalent prime focus geometry. Figure 19 shows the concept. In essence, the subreflector and main reflector are replaced by a paraboloidal reflector with a very long focal length. The ratio of this length to the true main reflector focal length is termed the magnification factor. The equivalent antenna consists of this paraboloid being fed by the unaltered Cassegrain feed horn.*

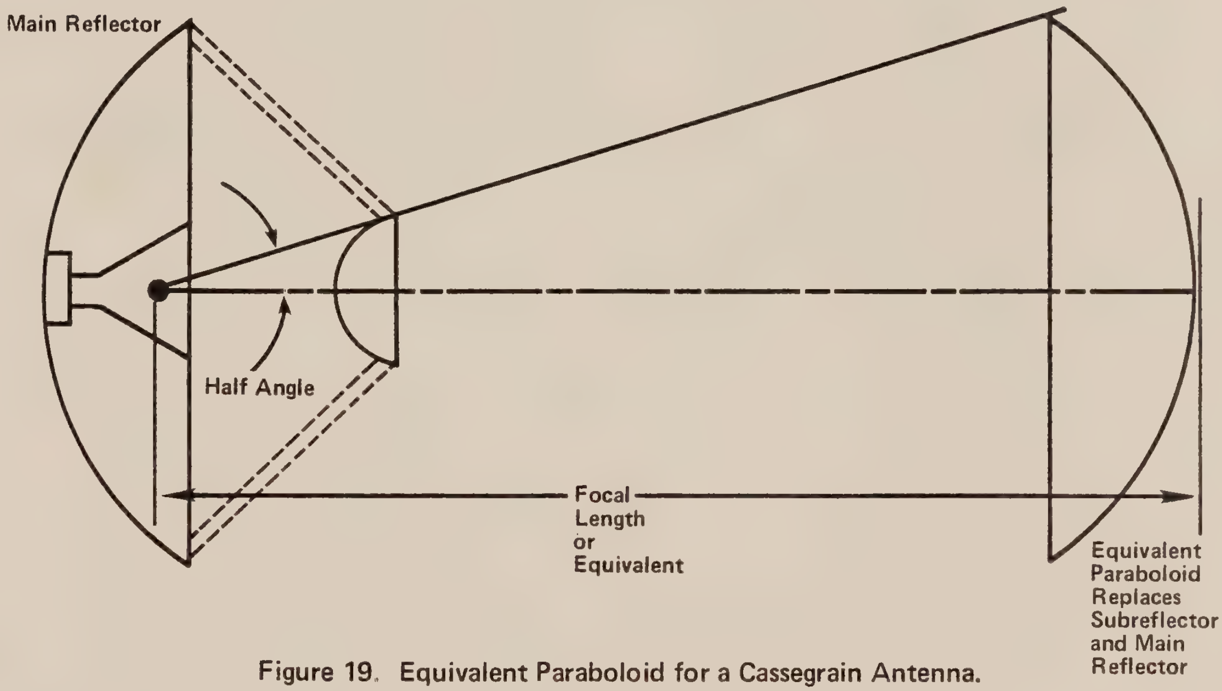



Figure 19. Equivalent Paraboloid for a Cassegrain Antenna.

*Recalling that in a prime focus system the feed pattern determines the aperture amplitude distribution, and since the Cassegrain has an equivalent prime focus system, the same is true for a Cassegrain system. The subreflector and main reflector will essentially reproduce the feed pattern in the aperture plane. So the feed horn performance becomes critical to antenna performance.*

*Several types of feed horns are currently in use in earth station antennas: diagonal horns, corrugated horns, and multimode horns. The selection is dictated by RF specifications firstly — economics, weight, size, and fabrication techniques secondly.*

*A diagonal horn feed is often chosen when dissimilar transmit and receive patterns are desirable. This is the case for an antenna needing very low 6 GHz sidelobes and very high 4 GHz gain. Figures 20 and 21 show the radiation patterns of such a diagonal horn. Notice that the large taper (24 dB) at 6 GHz means low sidelobes and the 14 dB taper at 4 GHz means a near uniform aperture distribution and therefore high efficiency. A diagonal horn also is easily matched as shown by the VSWR curve of Figure 22 made on a production line horn and its orthomode transducer.*

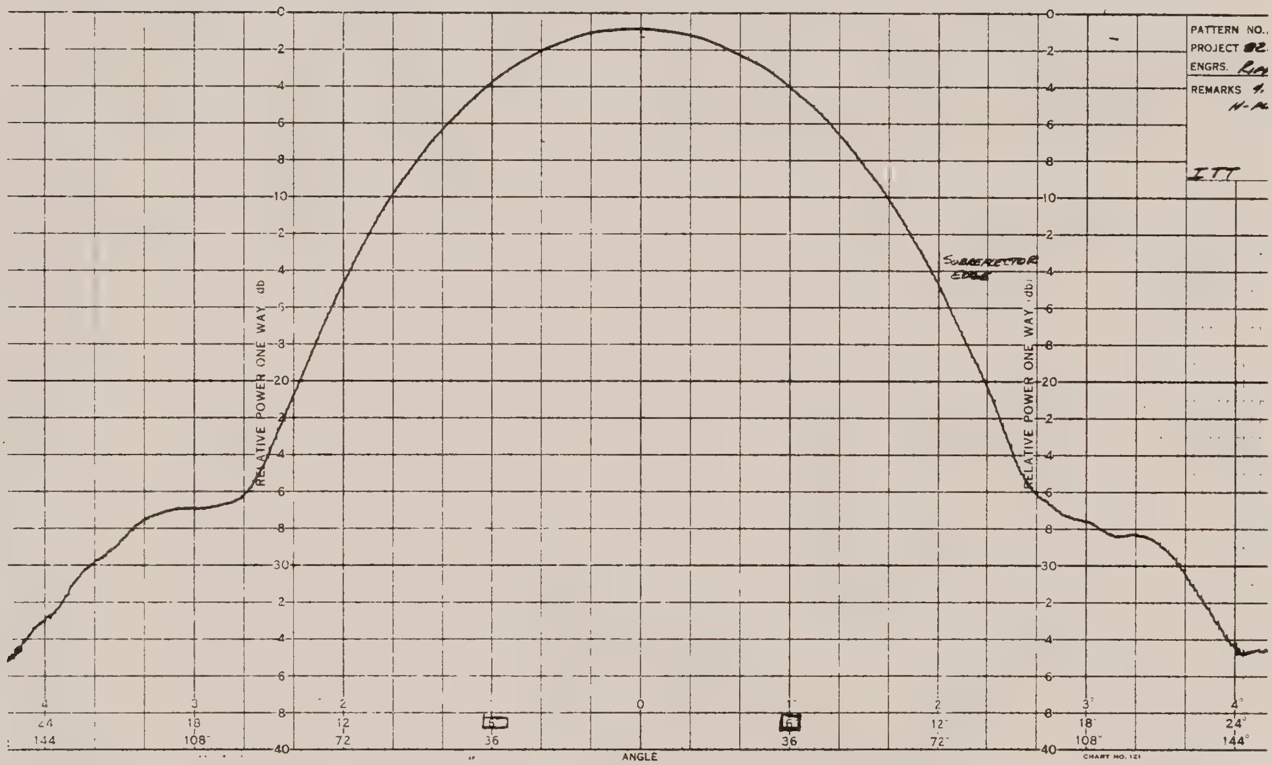



Figure 20. 4.2 GHz Diagonal Horn Pattern.

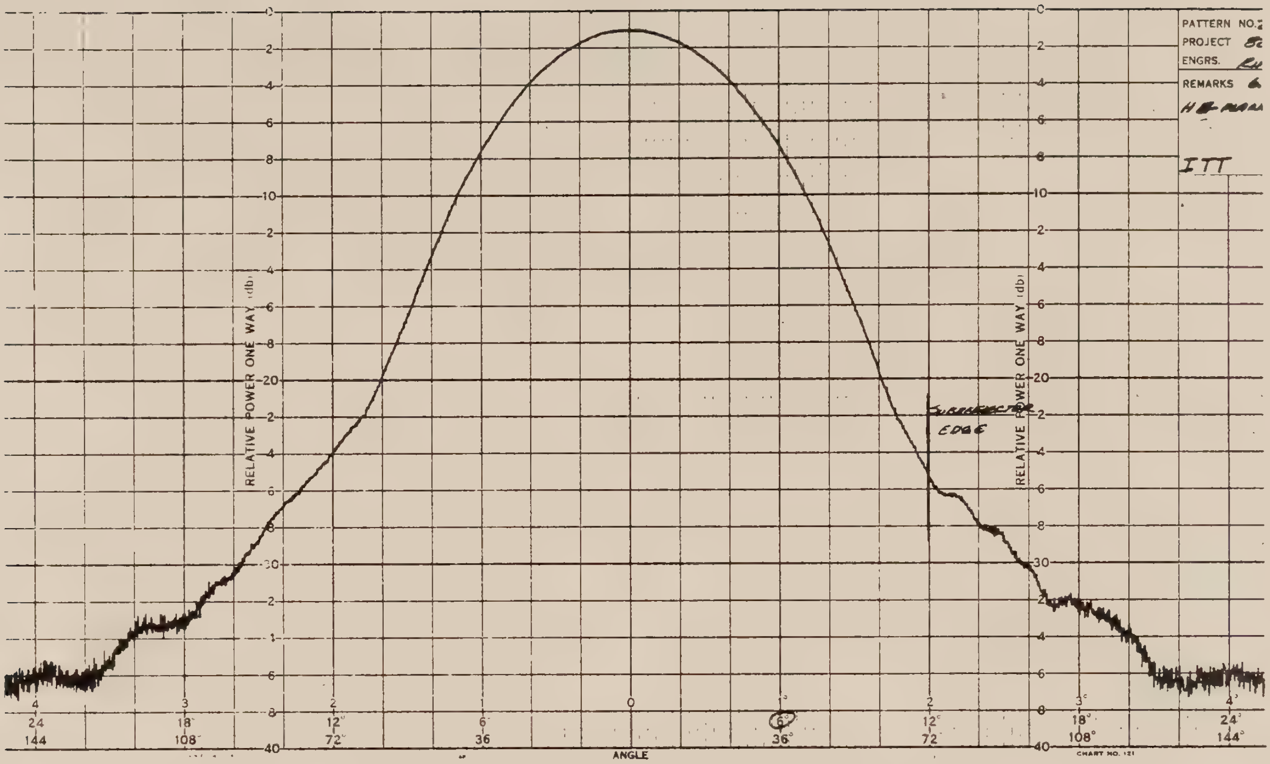



Figure 21. 6.175 GHz Diagonal Horn Pattern.

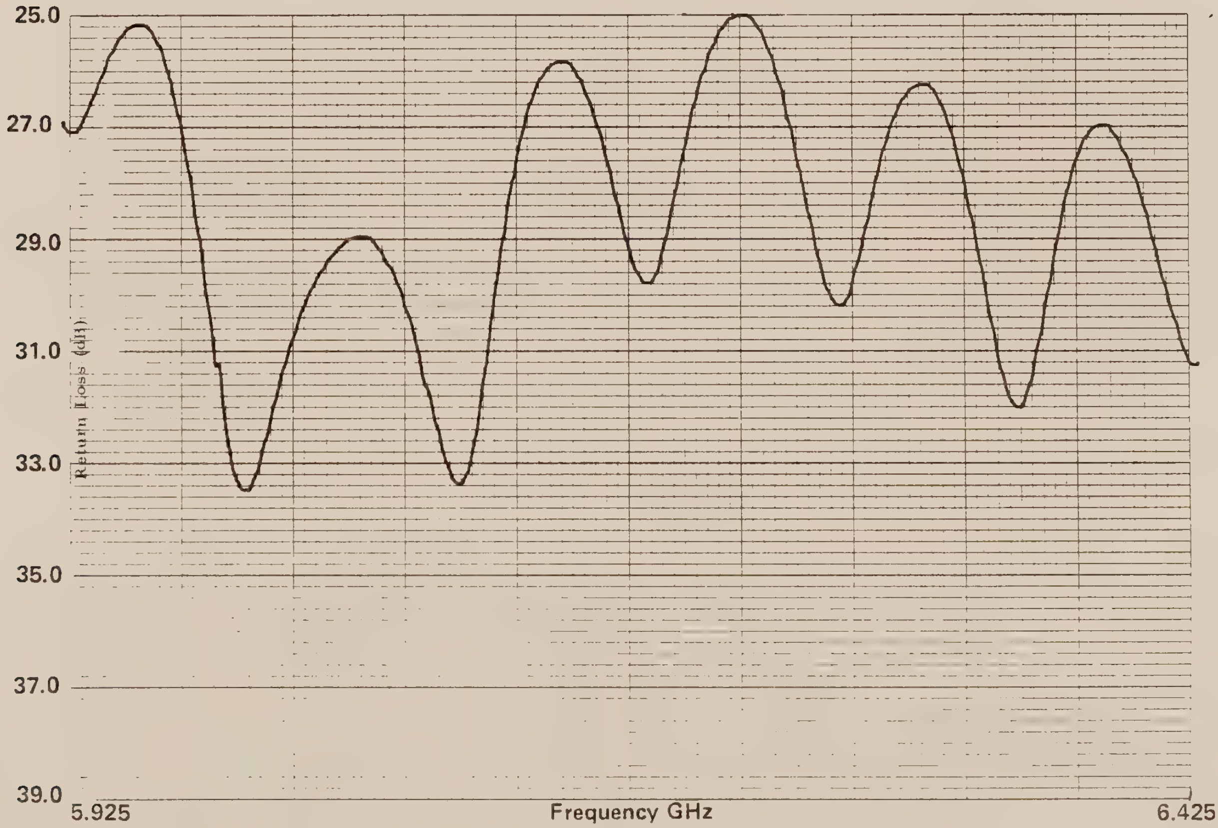



Figure 22. Series 8220 Feed Horn Return Loss vs. Frequency GHz.

*A corrugated feed horn is often used when the transmit and receive specifications are similar because it maintains a constant beamwidth over large frequency bands. This means the receive and transmit distributions will be similar, yielding similar efficiencies and sidelobes. Typical corrugated horn patterns are shown in Figures 23 and 24.*

*The multimode feed horn is also often employed in earth stations, usually to yield patterns similar to a corrugated horn but to avoid the costly machining of the horn.*

*These are, of course, rather general feed guidelines. Pattern shaping techniques are sometimes employed with all three horns.*

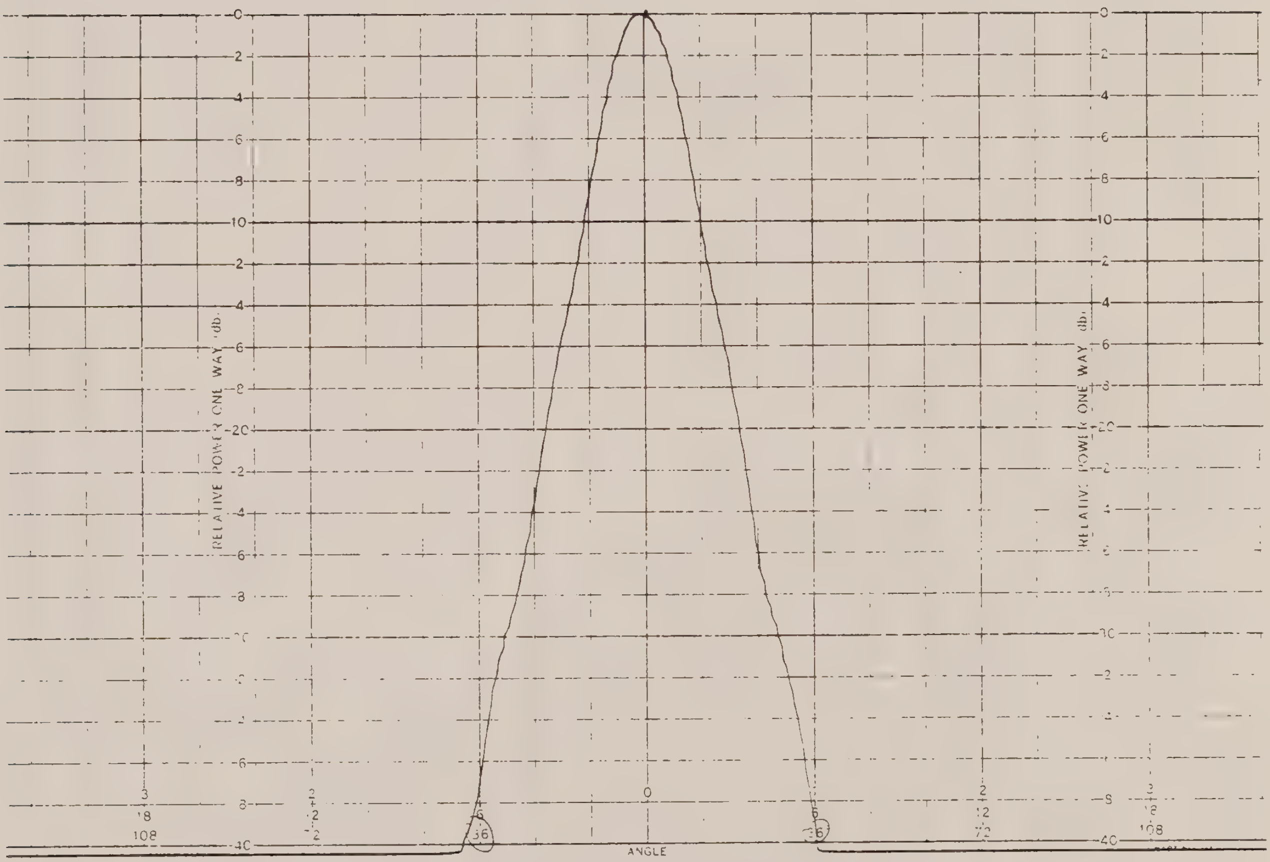



Figure 23. 3.95 GHz Corrugated Horn Pattern.

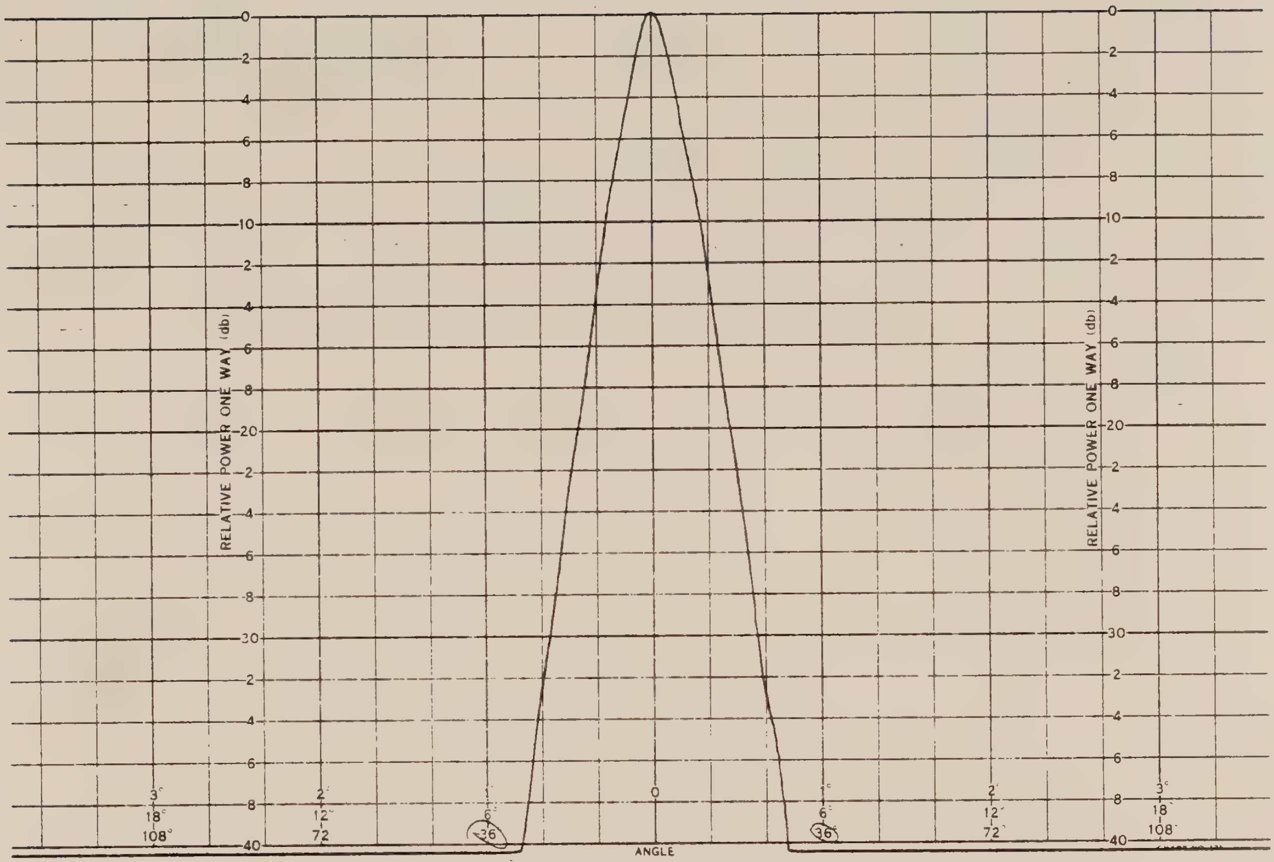



Figure 24. 6.175 GHz Corrugated Horn Pattern.

*In addition to affecting the aperture amplitude distribution the feed pattern determines the amount of energy spilled over past the subreflector. From Figure 25 it is obvious that to keep this energy loss low it is important that the feed pattern drop sharply beyond the subreflector. Not only will this improve the antenna gain but it will also prevent large sidelobe increases in the angular region around the subreflector. Notice from the patterns of Figures 26 and 27 that the sharper dropoff of the diagonal horn means lower sidelobes in the subreflector spillover region. So the Cassegrain design forces the designer into a compromise: either use a very high taper (low energy) on the subreflector edge to reduce the spillover, or suffer the subreflector spillover in order to have a more uniform distribution on the main reflector.*

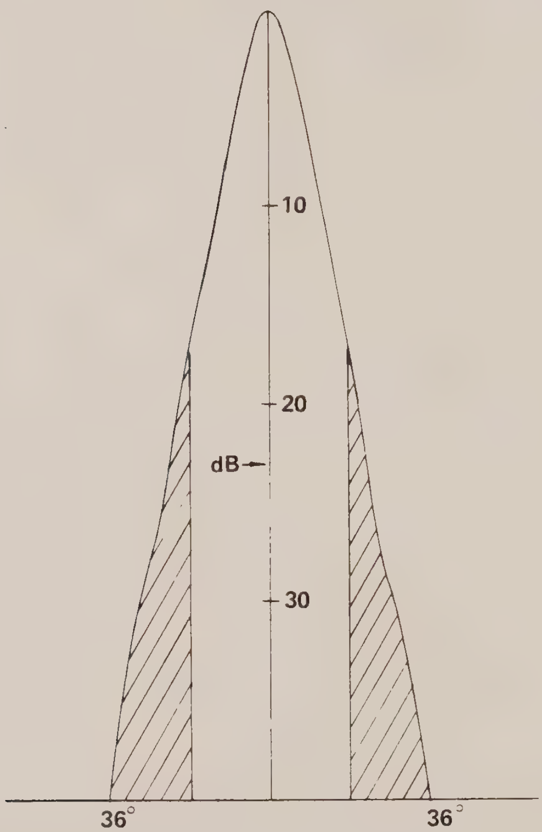



Figure 25. Typical Feed Pattern Showing Spillover Energy.

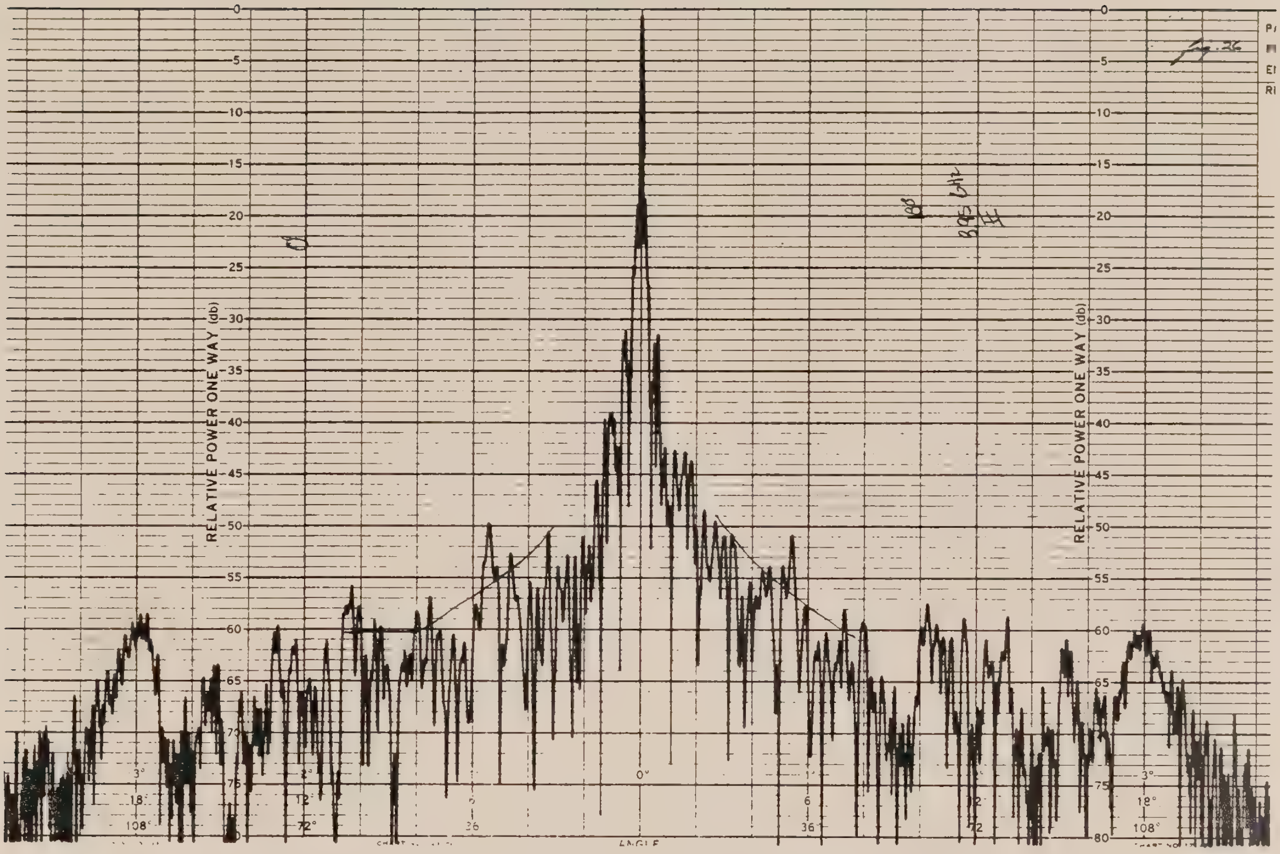



Figure 26. Pattern of a 10 Meter Earth Station with Diagonal Horn Feed.

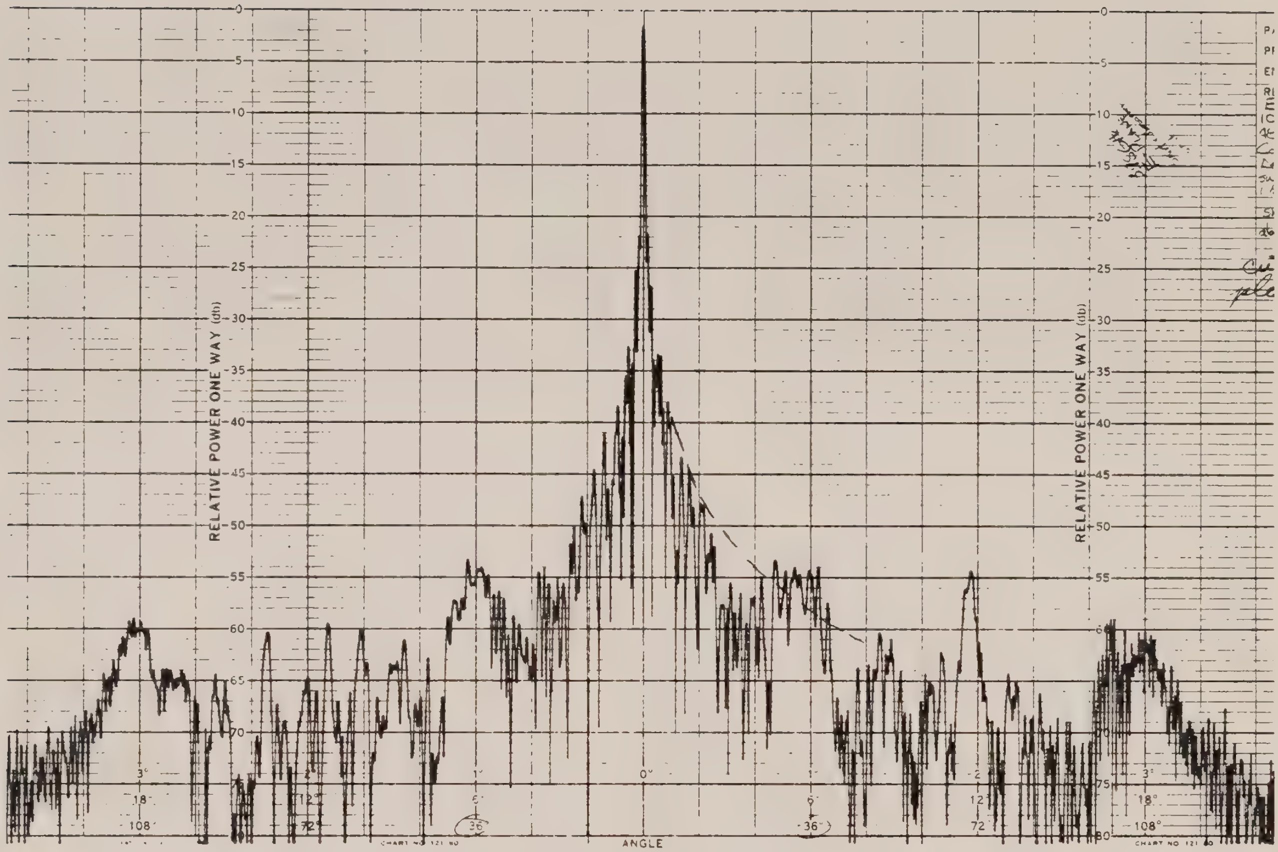



Figure 27. Pattern of Antenna of Fig. 26 with Corrugated Horn Feed.

*Shaped reflector systems were devised to overcome this Cassegrain compromise. The idea is to so shape the reflectors that a large energy taper on the subreflector will still produce an aperture distribution nearly uniform in both phase and amplitude. The subreflector and main reflector coordinates are usually calculated numerically by computer, with no closed form solution for the surfaces ever being determined. Both reflectors are still surfaces of revolution but they are no longer a hyperboloid and paraboloid.*

*While shaped system coordinates are actually the solution of several simultaneous equations, it is helpful to imagine the shaping process as follows: we wish to keep the spillover energy low so we use a narrow feed pattern. But this means a large subreflector edge taper and so a large main dish taper. The main dish is being utilized inefficiently since its outer area has very little energy on it. So we shape the subreflector to redistribute the energy, throwing some of what hits near its center toward the outer portion of the main dish. Next we correct the main reflector to restore uniform phase across the aperture with the shaped subreflector.*

*A typical partial computer printout for a shaped systems' coordinates is shown in Figure 28. The parameters input in this case are subreflector size, main reflector size, half angle to the subreflector, feed location, feed pattern shape, and aperture distribution.*

```
? 30.,222.,20.,0.,80,0,.631,222,0,158.

SHAPED REFLECTOR PROGRAM     MODIFIED FOR CORRUGATED HORN

MAIN REFLECTOR DIAM. =     444.00 INCHES

SUBREFLECTOR DIAM. =     60.00 INCHES

HALF ANGLE TO SUBREFLECTOR =     20.00 DEGREES

FEED DISTANCE FROM APERTURE PLANE =     0.     INCHES

TAPER ON SUBREFLECTOR =     -21.61 DB

TAPER ON MAIN REFLECTOR =     -4.00 DB
```

| X2 | Y2 | X1 | Y1 | THETA1 | THETA2 | Y0-Y2 |
|---|---|---|---|---|---|---|
| 222.0000 | -.0000 | 30.0000 | 0. | 20.0000 | 66.7665 | .0000 |
| 221.0000 | .6600 | 28.2329 | .7739 | 19.0742 | 66.8778 | .0409 |
| 220.0000 | 1.3205 | 26.9956 | 1.3267 | 18.4114 | 66.8762 | .0783 |
| 219.0000 | 1.9805 | 26.0352 | 1.7613 | 17.8883 | 66.8154 | .1129 |
| 218.0000 | 2.6395 | 25.2460 | 2.1218 | 17.4524 | 66.7178 | .1454 |
| 217.0000 | 3.2971 | 24.5736 | 2.4310 | 17.0767 | 66.5950 | .1760 |
| 216.0000 | 3.9535 | 23.9550 | 2.7175 | 16.7276 | 66.4607 | .2047 |
| 215.0000 | 4.6078 | 23.3270 | 3.0094 | 16.3694 | 66.3290 | .2324 |
| 214.0000 | 5.2605 | 22.6875 | 3.3081 | 16.0009 | 66.2005 | .2585 |

Figure 28. Computer Printout for Dual Shaped Reflector Coordinates.

*A dual shaped system is capable of efficiencies of 65–80%. A gain budget for such a system designed for 68% efficiency is shown in Figure 29. This particular system has a 9 dB "uptaper". That is, the geometry of the system uses a 13 dB subreflector taper to produce a 4 dB main dish taper. Subreflector diffraction must then of course, be accounted for.*

| Gain Factors | 4000 MHz | 6000 MHz |
|---|---|---|
| *Gain of Ideal 10 Meter Antenna* | *52.50 dBi* | *56.02 dBi* |
| *Aperture Illumination Efficiency* | *-0.09 dB* | *-0.50 dB* |
| *Gain of Ideal 10 Meter Antenna* | *52.50 dBi* | *56.02 dBi* |
| *Aperture Illumination Efficiency* | *-0.09 dB* | *-0.50 dB* |
| *Spillover for Main Reflector* | *-0.10* | *-0.06* |
| *Spillover for Subreflector* | *-0.60* | *-0.50* |
| *Blockage Due to Subreflector and Spars* | *-0.35* | *-0.64* |
| *Surface Tolerance* | *-0.13* | *-0.30* |
| *Primary Pattern Phase Error* | *-0.12* | *-0.20* |
| *Cross-Polarization Loss* | *-0.06* | *-0.10* |
| *Loss in Horn–Orthomode Assembly (including mismatch)* | *-0.20* | *-0.20* |
| *Gain at the Output of the Orthomode Transducer* | *50.85 dBi* | *53.5 dBi* |

Figure 29. Gain Budget for a 10 Meter Dual Shaped Antenna.

*To illustrate how main dish taper affects gain, Figure 30 lists illumination efficiencies for various 1–(1-A)p² tapers. As with all antennas however, the more uniform distributions represent generally higher sidelobes.*

| Edge Taper (A) (dB) | Voltage | Illumination Efficiency (%) | Gain Loss (dB) |
|---|---|---|---|
| 0 | 0 | 100 | 0 |
| 1 | .891 | .999 | .005 |
| 2 | .794 | .996 | .019 |
| 3 | .708 | .990 | .042 |
| 4 | .631 | .983 | .074 |
| 5 | .562 | .975 | .112 |
| 6 | .501 | .965 | .157 |
| 7 | .447 | .954 | .207 |
| 8 | .398 | .942 | .206 |
| 9 | .355 | .930 | .317 |
| 10 | .316 | .918 | .374 |
| 15 | .178 | .860 | .654 |
| 20 | .100 | .818 | .875 |

Figure 30. Illumination Efficiency vs. Taper for a 1-p²(1-A) Voltage Distribution.

*Shaping techniques offer several advantages besides a more uniform distribution. For instance, a standard Cassegrain system has a gain loss due to subreflector blockage firstly because that area of the aperture is unusable and secondly because the system puts energy into that wasted area. Shaped designs allow the designer to direct no energy into the central blocked region thereby allowing blockage to reduce gain only by a loss in area. In addition, this means no energy is directed back toward the feed horn so that subreflector caused group delay is nearly eliminated.*

*Another shaping technique is possible with reflectors large in terms of wavelengths, about 150 $\lambda$ or greater. This technique maintains a high energy level on most of the main reflector but drops it sharply near the periphery. The result is low sidelobes in the dish spillover region and yet a reasonably high efficiency.*

*Other variations of shaped systems are possible. Figures 26 and 27 show patterns of a shaped reflector used with a shaped subreflector other than the one which it was originally designed with. Still another possibility is to carefully design a shaped subreflector for use with a standard paraboloidal reflector. The resultant small phase error is normally tolerated, with overall efficiencies ranging from 60 to 65%.*

*In all reflector antennas, dual reflectors included, objects in the aperture affect sidelobes. This is shown in Figure 31 where two spars of the antenna of Figure 26 were replaced with small guy wires. Notice that the pattern is affected in nearly all regions.*

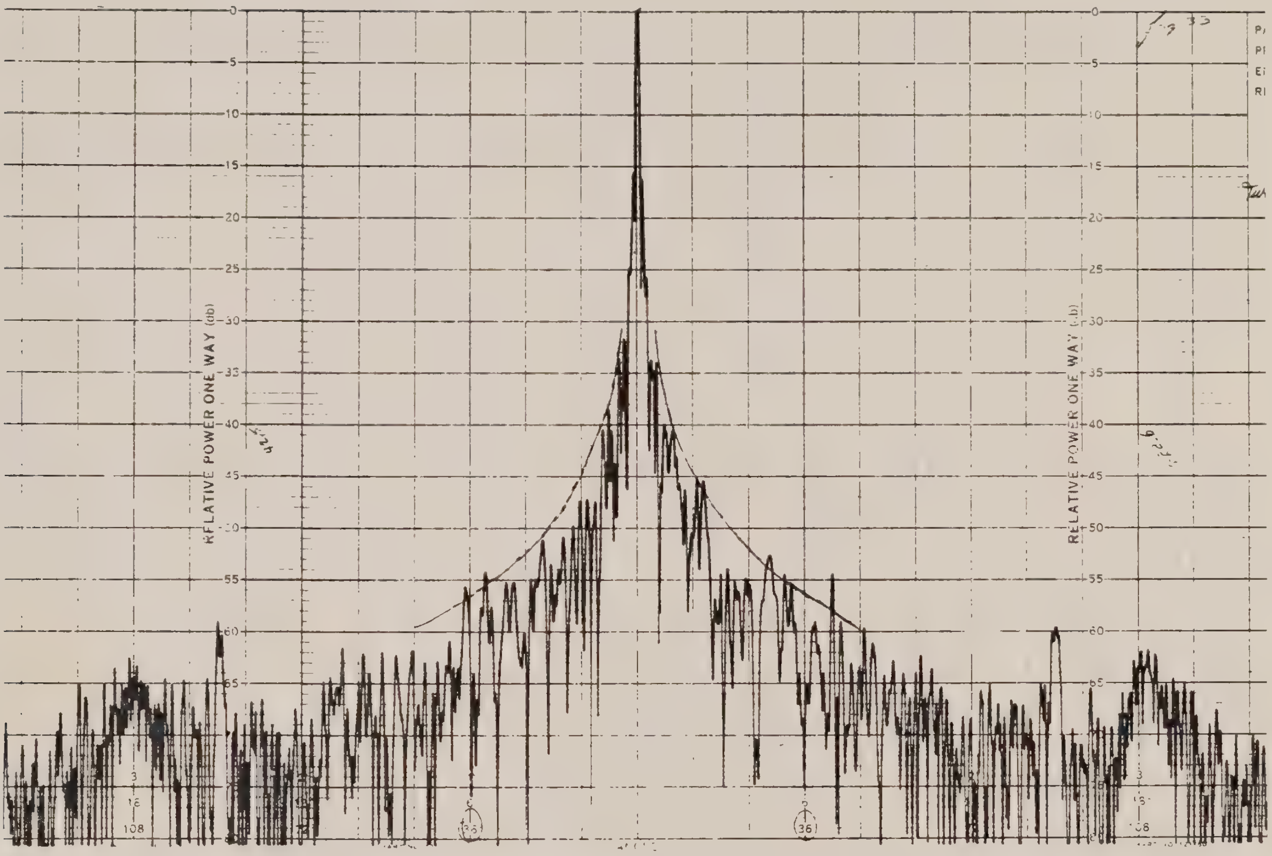



Figure 31. Same Pattern as Figure 26 but with 2 Spars Replaced by Guy Wires.

**Comparisons** *A general rule of thumb for earth stations in the 10 meter range is: if patterns are of prime importance, use a prime focus antenna; if gain is the critical parameter, use a dual shaped system. For example, a comparison of the pattern of Figures 32, 33, and 12, 13, shows the prime focus design to have superior sidelobes, facilitating antenna coordination and site selection. This is primarily due to the near elimination of blockage and diffracting and scattering contributors (spars and subreflector).*

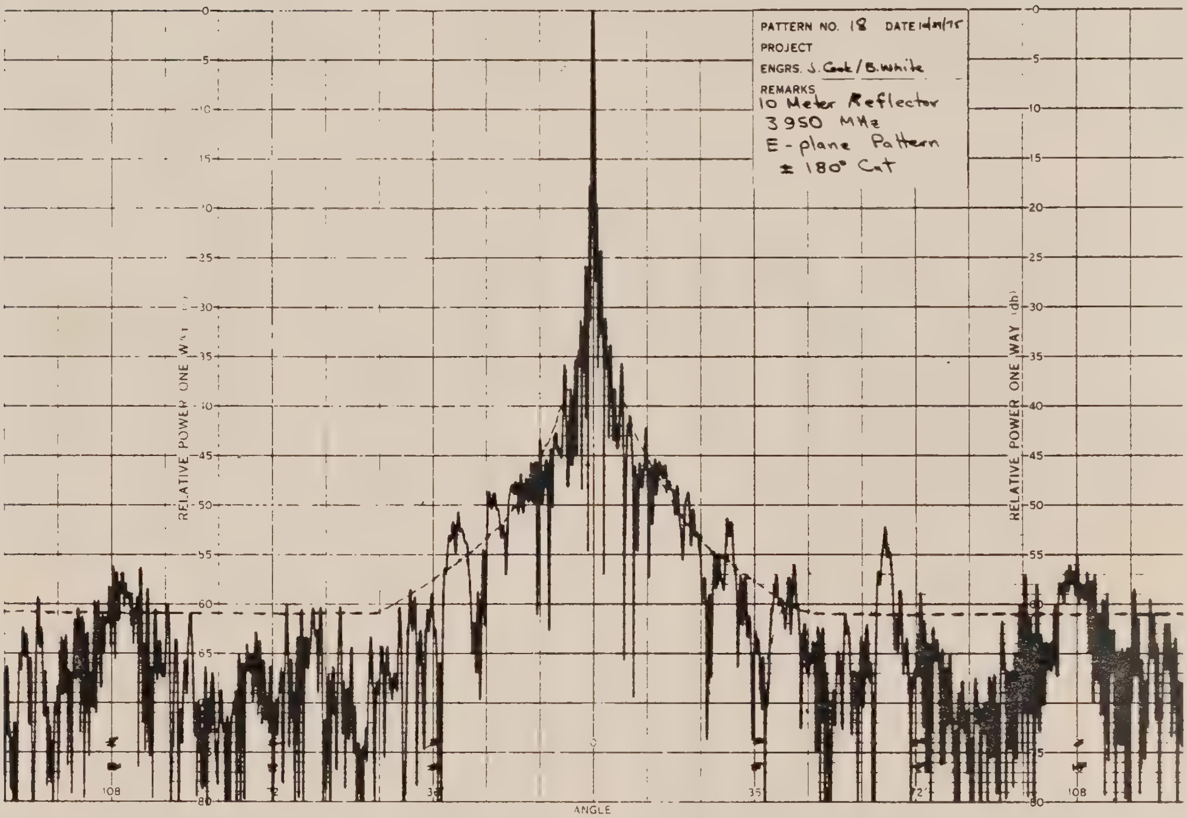



**Figure 32. Typical 4 GHz Pattern of 10 Meter Dual Reflector Antenna.**

*The improved sidelobes of a prime focus design are not gratis, however. They are payed for with reduced gain. The antenna of Figure 34 provides 0.65 dB more receive band gain than the prime focus antenna of Figure 12. 0.4 dB is attributable to an aperature efficiency increase and 0.25 dB to a reduced length of waveguide, assuming the LNA is located in the reflector hub.*

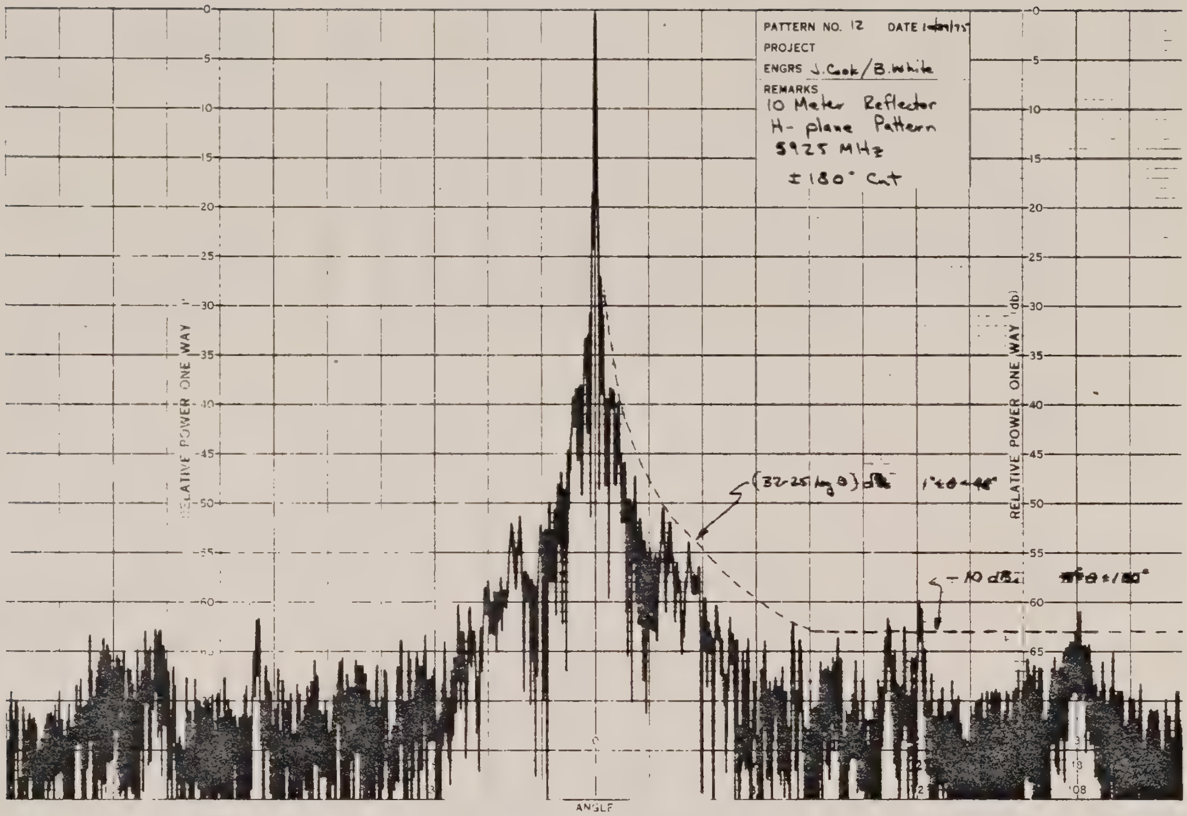



Figure 33. Typical 6 GHz Pattern of 10 Meter Dual Reflector Antenna.

*This 0.25 dB resistive loss not only reduces gain but it adds 16 °K of noise to the system. This noise increase along with the 0.65 dB gain decrease means a 1.5 dB G/T reduction in a typical system with a 55 °K LNA. EIRP can similarly be about 0.8 dB higher with dual reflector systems.*

*Polarization requirements often dictate the use of dual reflector antennas. Both the prime focus and dual reflector antennas of Figures 12, 13 and 34, 35 are equipped with feeds which are rotatable from the reflector hub, so they are both suitable for simple polarization adjustment. However, such schemes as polarization tracking, whether it be programmed Faraday correction or polarization auto-tracking, call for the vertex mounted feed of a dual reflector system.*

*The complexity of an autotracking feed (i.e., feed for an AZ-EL autotrack system) also normally requires a dual reflector geometry.*

References

1. *"A Simplified Approach to Cassegrain Antennas", William T. Whistler, Electronic Design, January 20, 1964, p.44.*
2. *"RF Design of Communication Satellite Earth Stations", Cuccia Williams, Cobb Rahilly, Microwaves, July, 1967.*
3. *"Microwave Antenna Theory and Design", by Samual Silver, 1964, Dover Publications, N.Y.*

# THE SMALL ANTENNA FOR SATELLITE COMMUNICATIONS

Marvin Shoemake
Product Line Manager
Satellite Communications Antenna Products

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Introduction** The FCC's declarative action accepting small earth station antennas, 4.5 meters in diameter or larger, and its ruling that filings using small earth station antennas would be routinely granted has brought about an overwhelming interest in this relatively low cost antenna within the communications industry. This paper will describe the small earth terminal antenna, its performance impact, and present a discussion of Scientific-Atlanta's 5 meter earth station antenna.

**Performance Requirements** The FCC has established specific performance requirements for the satellite earth terminal employing small antennas in Declaratory Ruling and Order RM 2725, FCC 76-1169. It is the responsibility of the applicant to outline his specific requirements and provide proof that the requirements are adequately achieved with the proposed antenna. The two most important performance criteron is the antenna gain and secondary pattern characteristics. The gain must meet the guidelines of other system parameters to provide carrier-to-noise margins which are at least 3.65 dB above receive system noise threshold. This is the minimum margin, as established by the FCC, which is sufficient to insure that satellite link degradations do not drop the received carrier level below threshold. The site location, satellite EIRP, elevation angle, and other receive system components in addition to the antenna gain serve to establish the receive carrier-to-noise level for any given system. A typical computer technical analysis of a small earth station and the resultant carrier-to-noise calculation is given in Table 1. Because of the initial cost and maintenance factors associated with very low noise amplifiers it is desirable that the aperture efficiency of the small antenna be used to the fullest extent possible. The analysis in Table 1 shows that the system G/T and downlink carrier-to-noise is directly affected dB for dB by the antenna gain.

The small antenna secondary pattern characteristics play a vital role in frequency coordinating the selected earth station site. The very congested frequency spectrum in the 4 and 6 GHz bands from terrestrial microwave systems makes coordination sometimes difficult. In addition, the antenna pattern is a key factor in interference protection from adjacent satellites. The FCC in the declaratory ruling defined pattern requirements for the small earth station antenna. Figure 1 is a plot of pattern requirements as set forth in the ruling. An antenna with pattern characteristics within the criteron will insure future interference protection once the site has been initially coordinated and filed with the FCC.

The pattern requirements can be achieved with several types of antennas and feeder configurations if careful design techniques are employed. The reflector antenna is the most widely used and accepted type of antenna primarily because it fits more readily the system antenna requirements, but it also is desirable from a construction simplicity, economic, availability, and transportability standpoint. Other types of antennas which provide some pattern improvement over the conventional reflector antenna are the shrouded horn reflector and shrouding techniques on conventional reflectors. However, these antennas tend to negate the advantages mentioned previously, they are more costly initially and maintainability on the environmental exposed shrouds and associated microwave absorber must be questioned. In the case of the radome covered aperture of the horn antenna, the attenuation through the water film build up on the radome during rainfall periods could degrade the receive system carrier-to-noise below threshold.

TECHNICAL ANALYSIS OF A SMALL RECEIVE-ONLY EARTH STATION
FOR A CABLE TELEVISION SYSTEM

| | |
|---|---|
| NATIONAL CABLE COMPANY | E. LANSING, MI.<br>42D 40M 50S LATITUDE<br>84D 27M 37S LONGITUDE |

SMALL EARTH STATION TECHNICAL CHARACTERISTICS
---------------------------------------------

| | | | | |
|---|---|---|---|---|
| ANTENNA | MANUFACTURER | S-A | SATELLITE RANGE | 70-136DEG |
| | MODEL | 300KR | MINIMUM ELEVATION ANGLE = | 0.0DEG |
| | SIZE | 5.0 METERS | | |
| | GAIN | 44.5 DBI | ANTENNA TEMPERATURE = | 19.3K |
| LNA | MANUFACTURER | S-A | RECEIVER MANUFACTURER | S-A |
| | MODEL | SA45183 | MODEL | SA 414 |
| | NOISE TEMP | 120.0K | FM THRESHOLD | 10.0DB |

T(SYSTEM) = T(ANT) + T(LNA)/GFEED + T(RCVR)/((GFEED)(GLNA)) =142.2 K
G/T = G(ANT) - 10LOG(T(SYSTEM)) = 22.9 DB/K

DOMESTIC SATELLITE CHARACTERISTICS - SATCOM SATELLITE 119.0W
----------------------------------

| SATELLITE TRANSPONDER | EIRP(SAT) | G/TSAT | EIRP(ES) |
|---|---|---|---|
| 6 (3820.0 MHZ) | 34.4 DBW | -2.2 DB/K | 84.2 DBW |
| 8 (3860.0 MHZ) | 35.5 DBW | -2.2 DB/K | 84.2 DBW |
| 20 (4100.0 MHZ) | 35.5 DBW | -2.2 DB/K | 84.2 DBW |
| 22 (4140.0 MHZ) | 34.4 DBW | -2.2 DB/K | 84.2 DBW |
| 24 (4180.0 MHZ) | 35.5 DBW | -2.2 DB/K | 84.2 DBW |

PERFORMANCE EVALUATION BASED UPON SATELLITE TRANSPONDER 6

TECHNICAL ANALYSIS
----------------

I CARRIER-TO-NOISE CALCULATIONS

II CARRIER-TO-INTERFERENCE CALCULATIONS

III SIGNAL-TO-NOISE CALCULATIONS

**Table 1. Compucon Computer Analysis of C/N for a Typical Earth Station Site.**

I CARRIER-TO-NOISE CALCULATIONS

A) C/NU CARRIER-TO-NOISE OF THE SATELLITE UPLINK

C/NU = G/TSAT -LU -LMU -K -10LOG(B) + EIRP(ES)

WHERE- G/TSAT = -2.2 DB/K LU = 201.0 DB
K = -228.6 DBW/K
EIRP(ES) = 84.2 DBW B = 39.0 MHZ

AND- LMU = MISCELLANEOUS UPLINK LOSSES

| | NOMINAL(DB) | WORST CASE(DB) |
|---|---|---|
| ATMOSPHERIC ABSORPTION | 0.1 | 0.2 |
| EARTH STATION/SPACECRAFT POINTING | 1.0 | 1.0 |
| RAIN ATTENUATION | 0.2 | 0.7 |
| SYSTEM DEGRADATION | 0.7 | 0.7 |
| POLARIZATION | 0.1 | 0.1 |
| ALTERNATE SATELLITE | 0.0 | 1.7 |
| TOTALS | 2.1 DB | 4.4 DB |

C/NU (NOMINAL) = 31.5 DB C/NU (WORST CASE) = 29.2 DB

B) C/ND CARRIER-TO-NOISE OF THE SATELLITE DOWNLINK

C/ND = G/TES -LD -LMD -K -10LOG(B) + EIRP(SAT)

WHERE- G/TES = 22.9 DB/K LD = 196.2 DB
EIRP(SAT) = 34.4 DBW

AND- LMD = MISCELLANEOUS DOWNLINK LOSSES

| | NOMINAL(DB) | RANDOM (DB) |
|---|---|---|
| SATELLITE EIRP | 0.00 | 0.15 |
| ATMOSPHERIC ABSORPTION | 0.10 | 0.10 |
| RAIN ATTENUATION | 0.00 | 0.20 |
| EARTH STATION/SPACECRAFT POINTING | 0.30 | 0.00 |
| POLARIZATION LOSS | 0.10 | 0.10 |
| INTERFERENCE DEGRADATION | 1.00 | 0.00 |
| FM THRESHOLD MARGIN | 1.00 | 0.00 |
| WIND EFFECT | 0.00 | 0.40 |
| LNA TEMPERATURE | 0.00 | 0.35 |
| LONG TERM DEGRADATION OF SATELLITE | 0.40 | 0.40 |
| TOTALS | 2.90 DB | 0.75 DB R.S.S. |

C/ND (CLR SKY) = 13.8 DB C/ND (WORST CASE) = 10.2 DB

C) C/NTH CARRIER-TO-THERMAL NOISE

C/NTH(CLR SKY) = 13.7 DB C/NTH(WORST CASE) = 10.1 DB

MARGIN ABOVE RECEIVER FM THRESHOLD (WITH 10.0DB THRESHOLD)

FM MARGIN(CLR SKY) = 3.7 DB FM MARGIN(WORST CASE) = 0.1 DB

Table 1. Compucon Computer Analysis of C/N for a Typical Earth Station Site (continued)

The conventional reflector type antenna is generally available with either prime focus or dual reflector feeder configurations. Both of these configurations is capable, with careful design techniques, of achieving the required pattern characteristics. However, because the dual reflector feed system can provide aperture efficiencies in small antennas, 5 meters or larger, which are 10 - 15% higher than the prime focus feed it is generally the preferred feeder configuration. This improved aperture efficiency could mean 0.7 - 1.0 dB of additional gain and in the marginal earth station this could significantly reduce the system outage and degraded system performance.

Final arguments before the FCC concerning small earth terminal antennas dealt with the potential adjacent satellite interference to the earth terminal. The incoherent carrier level received at the antenna terminals from the adjacent satellite spaced 4° away in orbital arc is directly dependent on the pattern level in the direction of the adjacent satellite. Because of this, the pattern of the small earth terminal antenna should provide maximum side-lobe levels in the 4 - 8 degree region of 27 - 40 dBi to insure that carrier-to-interference performance requirements are met.

The mechanical performance requirements of the small antenna include a mount movement mechanism which is capable of pointing the antenna across the complete 70° to 135° west longitude orbital arc. The antenna and mount pointing mechanism must have the structural integrity to provide an antenna beam pointing stability of 0.1° in operational winds. Additionally, the pointing configuration should allow positioning of the antenna in a simple straightforward manner and provide a pointing accuracy such that the main beam may be easily positioned on the selected satellite.

The structural design of the antenna and mount must not only meet the stiffness and strength system requirements operationally, but also provide margins of structural safety during severe environmental conditions. The safe structures requirements of AISC should be a part of the antenna and mount structural design criteron.

To summarize, the small earth station antenna should provide the gain necessary for the receive system to operate at least 3.65 dB above noise threshold under ideal, clear sky, conditions. The secondary pattern characteristics must meet the envelope shown in Figure 1 as required by the FCC declaratory ruling. The antenna positioning system must provide complete 70° to 135° of orbital arc coverage and the complete antenna structure possess the stiffness and strength to accurately point and maintain the RF beam toward the satellite. A complete tabulation of a typical small earth station antenna requirements is outlined in Table 2.

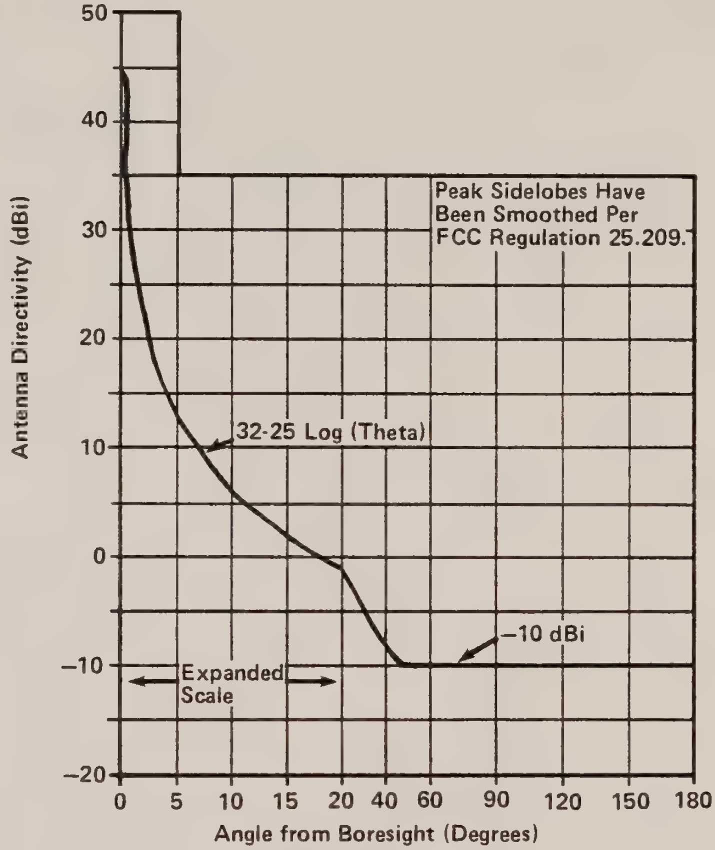



Figure 1 Small Earth Station Antenna Radiation Distribution Envelope

Table 2. Typical Small Earth Station Antenna Requirements.

ELECTRICAL CHARACTERISTICS

Operating Frequency Range
- Transmit
  - 5.925 to 6.425 GHz
- Receive
  - 3.70 to 4.20 GHz

Antenna Gain
- 44.5 dBi @ 4 GHz

Half-Power Beamwidth
- Transmit
  - 0.65°
- Receive
  - 0.9°

15 dB Beamwidth
- Transmit
  - 1.25°
- Receive
  - 2.0°

VSWR
- 1.3:1

Polarization
- Linear

Polarization Adjustment
- 360° continuous

Isolation (Receive-to-Receive) Dual-Pol
- 30 dB minimum

First Side Lobe
- −13 dB

Noise Temperature @ 30° Elevation
- 20° K

MECHANICAL CHARACTERISTICS

Antenna Size
- 5 Meter Diameter

Mount Type
- Elevation-over-Azimuth

Reflector Surface Tolerance
- Antenna Pointing Range
  - Azimuth 110° (2 overlapping sectors)
  - Elevation +15 to +60° continuous
- Pointing Accuracy
  - 0.03° rms in 30 mi/h winds gusting to 45 mi/h
  - 0.11° rms in 60 mi/h winds gusting to 85 mi/h
- Survival Wind Loads
  - 125 mph in any pointing direction
  - No stowing required 87 mph with 2″ radial ice

Operational Temperature Range
- −35 to +140° ;F

Total Weight (Reflector and Mount)
- 1500 lbm

**Scientific-Atlanta's Model 8008 5-Meter Earth Station Antenna.**

Scientific-Atlanta's small earth terminal antenna is shown in Figure 2. The 5 meter reflector is illuminated with a dual reflector high efficiency feed system. The antenna is supported and positioned with an elevation-over-azimuth mount. The development of this product is a culmination of many years of experience in satellite earth station antennas and brings to the industry an antenna with the following design features:

A. True elevation-over-azimuth mount configuration for universal coordinate system and ease of pointing to satellite.
B. 24 panel reflector design which allows field replacement of any damaged panel with no alignment required.
C. The 5 meter diameter antenna with high aperture efficiencies allows 0.5 - 0.7 dB of additional system margin over the minimum 4.5 meter small earth terminal antenna without sacrificing the economy of the small antenna.
D. Radiation patterns which meet or exceed the pattern envelope requirements as outlined by the FCC 25.209 of 32-25 log ($\theta$) dBi, $1° < \theta \leqslant 48°$ −10 dBi $48° < \theta \leqslant 180°$
E. Low shipping volume (260 $ft^3$) made possible by reflector "breakdown" design.
F. Can be assembled on rooftops accessible only by elevators.
G. Low shipping volume allows system to be hauled in by land rover or bush plane to remote sites.
H. Erection in remote inaccessible locations possible with erection kit.
I. Balanced single linkage adjustment system allows repositioning of antenna to another satellite by one man in a matter of minutes.
J. Azimuth and elevation position indicators at the mount in true azimuth and elevation angle readouts.
K. Adjustment mechanism allows positioning to any satellite within the 70° - 135° west longitude orbital arc at any site in the continental United States without replacing members.
L. LNA enclosure provided as a part of the reflector with possible redundant LNA mounting to rotatable feed plate eliminating the need for expensive and lossy flexible waveguide.
M. Unrestricted feed polarization rotation.

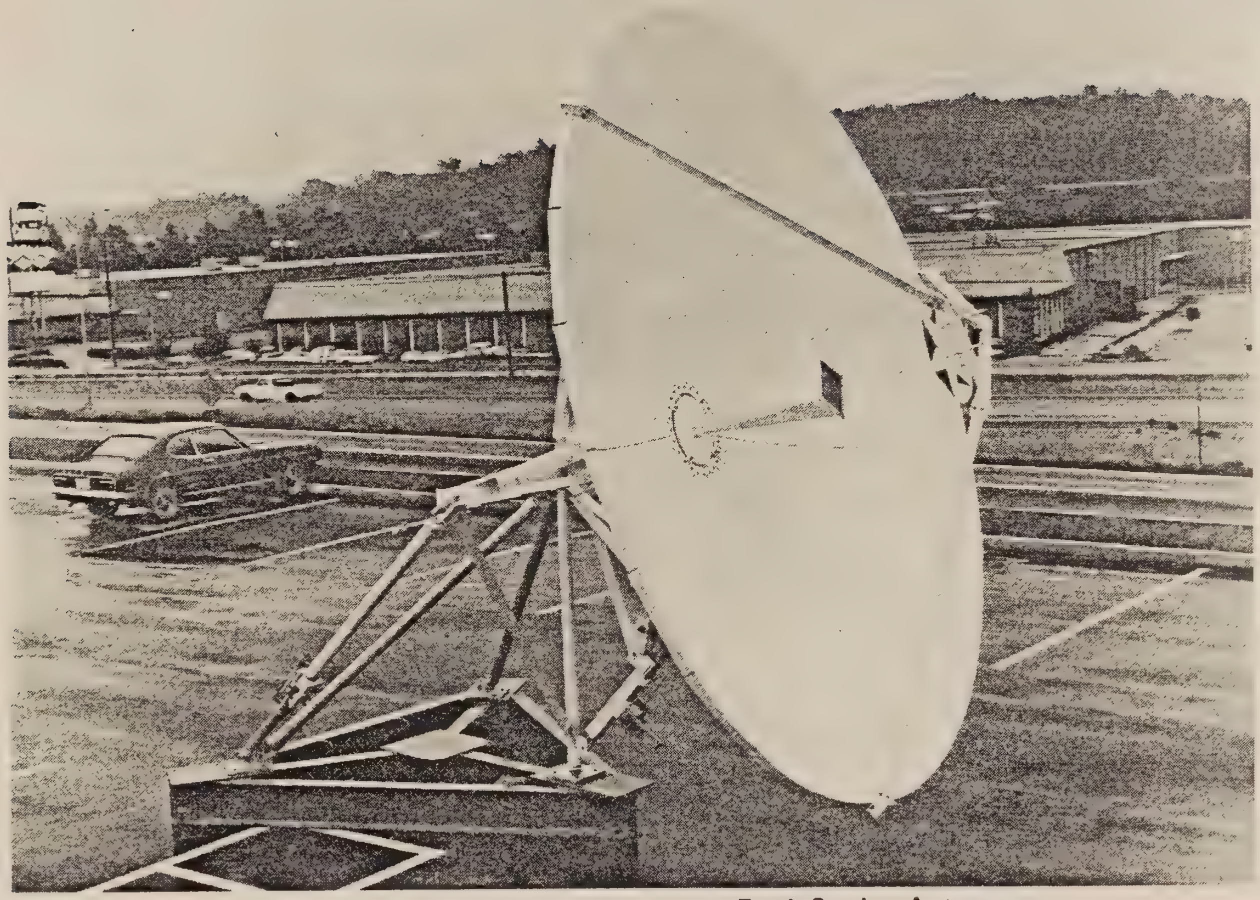


Figure 2. Model 8008 5 Meter Earth Station Antenna.

**RF Characteristics**

The 5 meter antenna provides additional aperture which is capable of delivering additional gain to the earth station system. It is advantageous because of the minimal margins in the small earth terminal system to design a feed system which can achieve the maximum efficiency from the 5 meter aperture. Scientific-Atlanta's design of such a feed system grown out of the many years of development and optimization of reflector type antennas. The dual reflector feed utilized in the 5 meter antenna is key to achieving efficiencies of 65% to 70%. A typical illumination scatter pattern of the dual reflector feed system is shown in Figure 3. The high efficiency 5 meter antenna provides .7 — 1.5 dB of additional gain over the FCC approved minimum aperture of 4.5 meter. During periods of degraded satellite links in marginal systems this could mean the difference between a degraded system performance and a complete outage condition. With Scientific-Atlanta's unique design and fabrication concept this larger antenna can be manufactured competitively with the smaller minimum aperture 4.5 meter antenna.

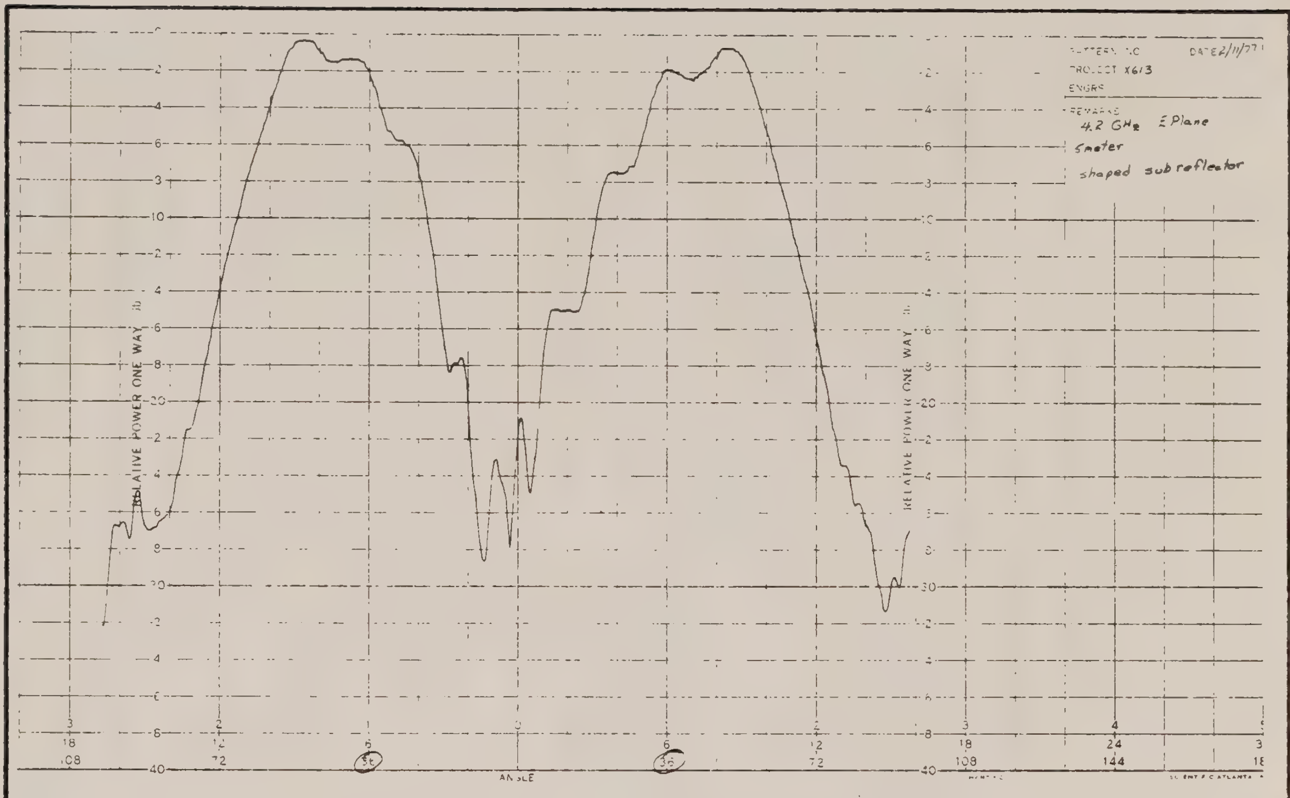



**Figure 3. Typical Illumination Scatter Pattern**

The secondary patterns produced by the 5 meter antenna are extremely important to the operation and coordination of the earth station terminal. The congested 4 and 6 GHz spectrum and the FCC pattern requirements of 32-25 log ($\theta$) dBi, $1° < \theta \leq 48°$; $-10$ dBi, $48° < \theta \leq 180°$ demands an antenna designed to control the spillover areas and the dual reflector edges. Also support spar configurations and shapes are of primary concern in controlling the wide angle sidelobes of the secondary patterns. A typical pattern of the Scientific-Atlanta 5 Meter Earth Station Angenna is shown in Figure 4. This pattern at the center of the 4 GHz receive band is the result of many years of experience in controlling wide angle sidelobes in reflector type antennas. The pattern is achieved without the use of cumbersome and costly absorber shrouding techniques. A shroud around the periphery of the reflector antenna aids in the control of the spillover region at the edge of the main reflector which reduces the wide angle sidelobes over a portion of the pattern angular region usually 90 to 120°. This advantage is overshadowed by the additional wind and ice loading to the reflector and mount which can be substantial in extreme environmental conditions. Also the shroud is lines with a microwave absorber which requires periodic maintance or replacement due to environmental exposure.

Of paramount concern in the satellite communications industry is future congestion within the geostationary arc. The reduction in satellite slot spacing and the potential adjacent satellite interference was one of the major stumbling blocks for the small earth station antenna. Additional pattern rejection to adjacent satellite interference is realized by increasing the antenna aperture size and as a result its directivity. The 5 meter antenna offers as much as 3.0 dB of additional rejection over the minimum 4.5 meter aperture.

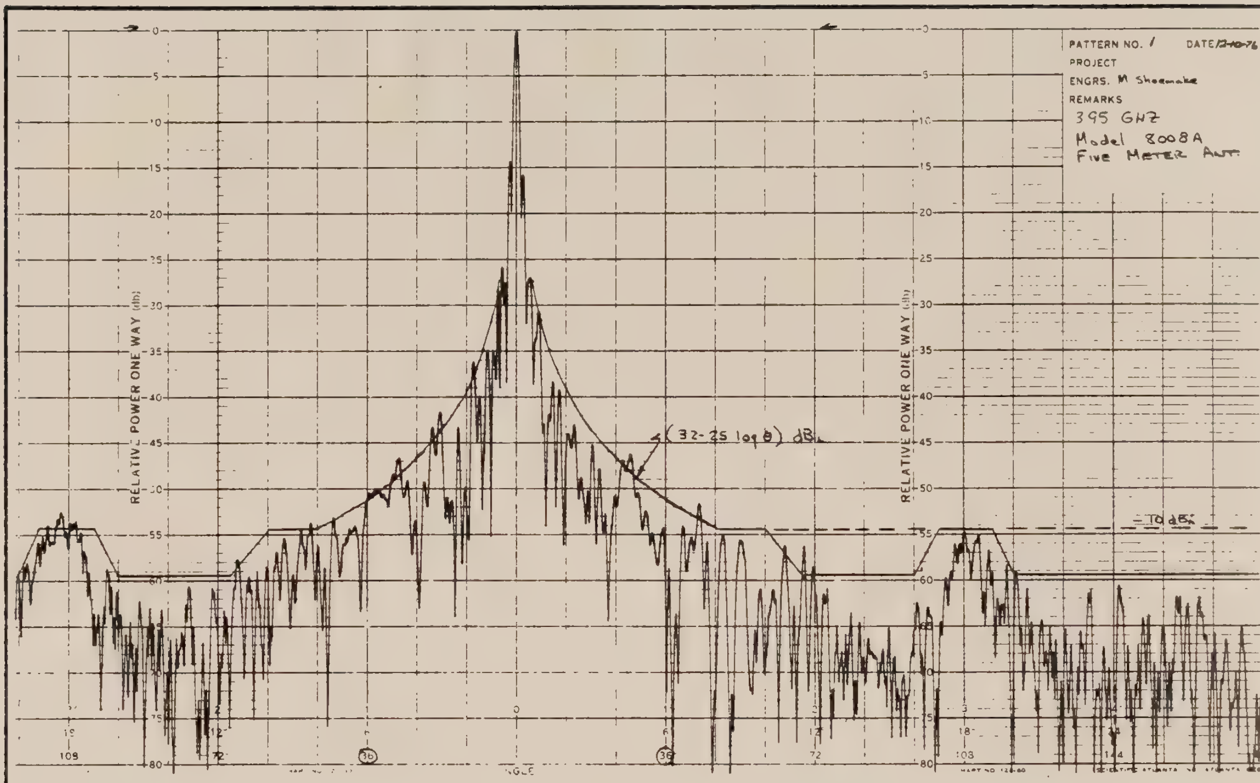



**Figure 4. Typical Secondary Pattern 5 Meter Earth Station Antenna**

**Mechanical Characteristics**

The basic mechanical design objectives of the Scientific-Atlanta 5 meter antenna were:

Cost Effectiveness
Structural Strength and Stiffness
Simplicity
Flexibility
Low Shipping Volume

During the past year, an extensive development program has been in process at Scientific-Atlanta which has achieved these design objectives.

The reflector design and fabrication technique is a unique approach to manufacturing reflector antennas. The 24 panel concept allows the normally large and cumbersome reflector to be broken down into very manageable and shippable panel sections. Each panel is stamped on match metal dies which gives a precise panel shape that is very repeatable. This low labor content technique is key to satisfying several of the objectives listed above. By investing in tooling to produce high volume precision parts Scientific-Atlanta is able to bring to the competitive marketplace a reflector with 3.7m$^2$ more area than the minimum 4.5 meter size requirements. The reflector panels are mounted to a hub assembly which also serves as an enclosure for a redundant LNA. A feed mounting for the LNA's has been incorporated into the design which allows rotation of the amplifiers with the feed polarization.

Pointing the 5 meter antenna at any satellite position within the 70° to 135° west longitude orbital arc is accomplished with an elevation-over-azimuth mount. The required movement to point from one end of the arc to the other varies with site location. The conventional mount axes design is straightforward and universally accepted coordinate system greatly simplifies the pointing process. This mount allows coverage of any domestic satellite from within the continental U.S. without the need for any structural member modifications.

The elevation-over-azimuth mount provides 110° of azimuth travel and 15° to 60° of elevation travel. Azimuth adjustment can be accomplished by one man in a matter of minutes since it is a balanced system movement of the telescoping adjustment mechanism is a simple adjustment. Location of the mechanism at the right foundation foot allows 85° of azimuth travel and relocating the hardware to the left foundation foot allows an additional 35° of travel with 10° of overlap. This is shown in more detail in Figure 5. .

The elevation adjustment mechanism is a hand wench operated device which provides an elevation angle operating range between 15 and 60 degrees. Again this adjustment is simple and can be accomplished by one man in a matter of minutes. A U-bolt clamping arrangement secures the mechanism and locks the antenna into place when the adjustment is completed. Figure 6 outlines the height above foundation for strategic points on the antenna as a function of elevation angle.

A direct elevation and azimuth indicator readout is provided on the mount for both adjustment axes as shown in Figures 7 and 8.

Mechanical testing on the reflector and mount included load and deflection testing to simulate load conditions of winds up to 125 MPH. The design was found to be well within the industry accepted AISC standards of 1.25 yield at maximum specified wind loading. Deflection tests verified design goals and pointing error budgets set forth for the system were achieved.

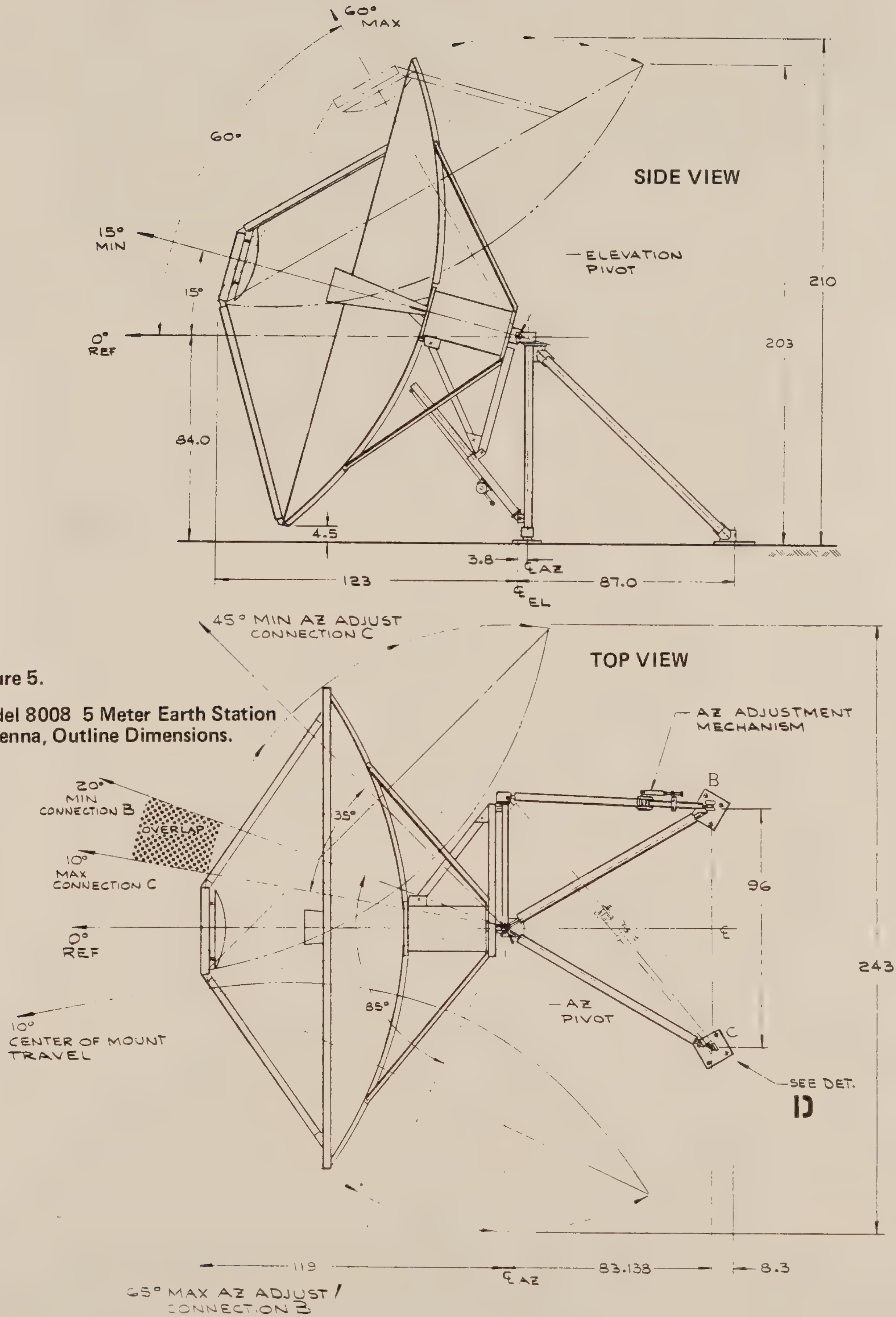



**Figure 5.**

**Model 8008 5 Meter Earth Station Antenna, Outline Dimensions.**

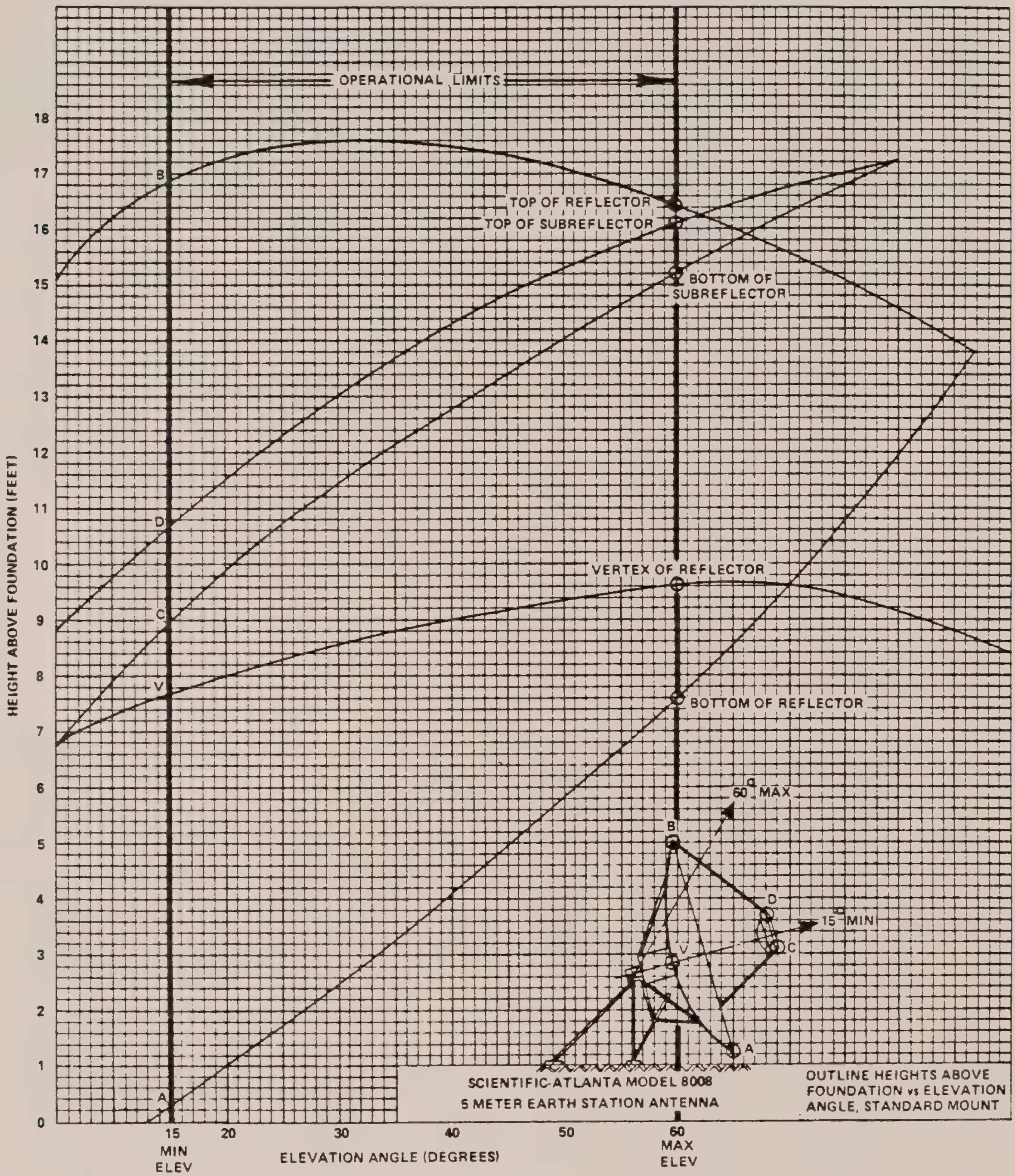



Figure 6. Model 8008 5 Meter Earth Station Antenna Outline Height above Foundation.

Figure 7. Elevation Position Indicator

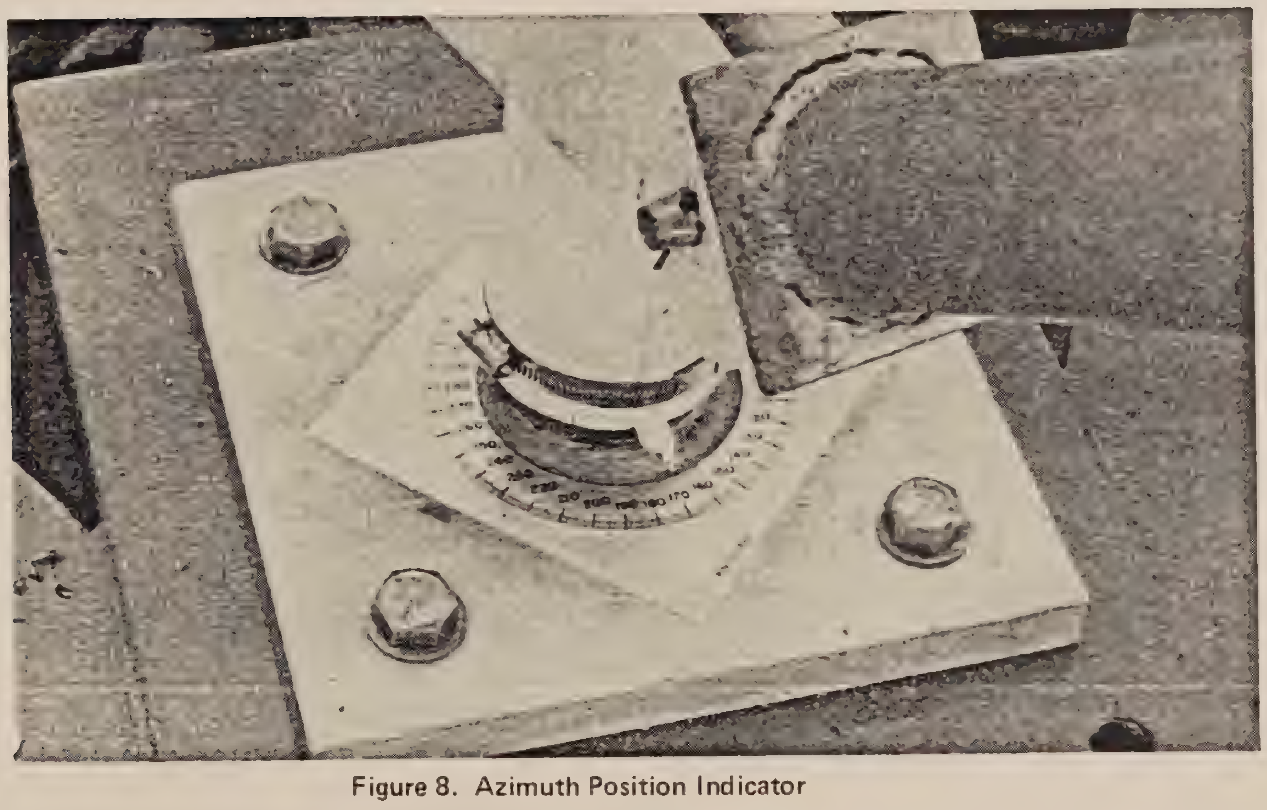


Figure 8. Azimuth Position Indicator

# ANTENNA NOISE

Marvin Shoemake
Product Line Manager
Satellite Communications Antenna Products

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## I. Introduction

*Over the years with the development of lower and lower noise receive systems it has become increasingly important to account for the noise received by the earth station antenna. Since this noise contributor has become an appreciable part of the total system noise, accurate prediction is a necessity to determining the receive system temperatures.*

*The noise received by an antenna is produced by black-body radiation from the various noise emitters surrounding the antenna. The intensity of noise power available at the antenna is the product of the emitters absorption coefficient and its ambient temperature. The fraction of this noise power actually received by the antenna is determined by the antenna's directivity in the direction of the noise emitter.*

*These noise emitters include the following components:*

a. *Cosmic noise*
b. *Atmospheric noise*
c. *Solar noise*
d. *Ground noise*

**II. Antenna Noise Temperature** *The total antenna noise temperature may be approximated by the following equation:*

$$T_a = \int_{\Omega_1} G_1 \left[ \frac{T_c}{L_T} + \left(1 - \frac{1}{L_T}\right) T_T \right] d\Omega_1 + \int_{\Omega_2} G_2 \left[ (1 - \rho^2)\, T_G + \rho^2 T_c \right] d\Omega_2 + T_s \qquad (1)$$

*where:*

$T_a$ = *Antenna temperature.*

$G_1$ = *The gain of the antenna in the direction which the antenna is receiving direct radiation from above the ground.*

$G_2$ = *The gain of the antenna in the direction which the antenna is receiving direct radiation from the earth.*

$\Omega_1$ = *The region of solid angle of the antenna pattern that is above ground level.*

$\Omega_2$ = *The region of solid angle of the antenna pattern that is toward the earth.*

$T_C$ = *The cosmic noise temperature.*

$T_T$ = *The atmospheric noise temperature.*

$T_G$ = *Ground noise temperature.*

$T_S$ = *Sun noise temperature.*

$L_T$ = *Atmospheric loss through the troposphere and lower atmosphere, includes the effects of moisture.*

$\rho$ = *Voltage reflection coefficient of the earth.*

*The above equation weights the noise power available from each source by the gain of the antenna in the direction of that emitting source. The integration over the total solid angle of the antenna pattern toward each emitter yields the total antenna temperature less the noise received from the sun. Because the location of this solar emitter, relative to the antenna is a seasonal as well as a daily variable, some average contribution must be assumed.*

*The following paragraphs briefly describe each noise source and its available noise power to the antenna.*

**III. Cosmic Noise** *Cosmic noise, or galactic background noise, is radiated by stars and other matter throughout interstellar space. It is at its maximum in the direction of the galactic center. Hogg and Mumford*[2] *give an approximate formula for average cosmic noise temperature as follows:*

$$T_C = \frac{2.6 \times 10^7}{f^2} \quad (^\circ K) \qquad (2)$$

*where f is the frequency of operation in MHz.*

**IV. Atmospheric Noise** *The major contribution to propagation medium loss at microwave frequencies is the troposphere and the moisture content of the low level atmosphere. The combination of these two contributors will be referred to as the atmospheric losses. At frequencies above 1 GHz the ionosphere has a negligible effect to propagation medium loss. The effective noise temperature is then given in the following equation:*

$$\text{Propagation Medium Noise Temperature} = \left(1 - \frac{1}{L}\right) T_T \qquad (3)$$

*where L is the atmospheric loss*

*and $T_T$ is the tropospheric temperature; usually considered to be 290° K*

*The atmospheric attenuation is the single largest contributor to antenna noise temperature at angles greater than 15° above the horizon for high gain antennas. It is necessary therefore to approximate these losses with a reasonably high degree of accuracy. Hogg and Semplak*[3] *have developed an expression for determining these losses. Figure 1 gives typical values which were obtained from the expression in dB/KM vs. frequency.*

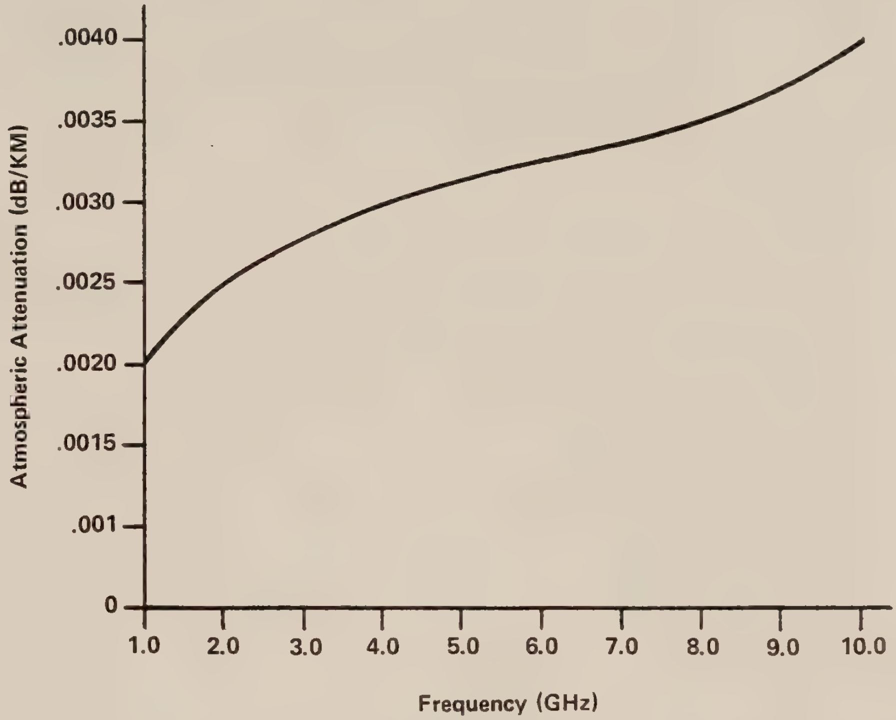



**Figure 1** Typical atmospheric attenuation vs. frequency for average Weather with $H_20$ vapor content of 10 gm/M $^3$.

*The values in Figure 1 also agree very closely with those obtained by Blake[1] for the one-way attenuation of the propagation medium.*

*The path length through the lower atmosphere and the troposphere varies with elevation angle, at zenith it is usually considered to be 15 KM. This was the value used to determine the data given in Figure 1. At other angles this height may be calculated from the following equations:*

$$H_T = (R_e + h)\,\frac{\sin B}{\cos\theta} \tag{4}$$

*where:* $\theta$ = *angle above horizon*

$R_e$ = *radius of the earth*
$h$ = *troposphere height at zenith*
$B$ = *angle at earth center between antenna and troposphere height*

*and*

$$B = \cos^{-1}\left[\left(\frac{R_e}{R_e + h}\right)\cos\theta\right] - \theta \tag{5}$$

V. Solar Noise

*The sun is an important contributor to antenna noise, even when only the low sidelobe region is directed towards this powerful source. At the frequency of interest, Van De Hulst[4] gives the temperature of the quiet sun as shown in Table 1.*

| Frequency (Mc) | Noise Temperature (°K) |
|---|---|
| 100 | $1 \times 10^5$ |
| 200 | $9 \times 10^5$ |
| 300 | $7 \times 10^5$ |
| 600 | $4.6 \times 10^5$ |
| 1,000 | $3.6 \times 10^5$ |
| 3,000 | $6.5 \times 10^4$ |
| 10,000 | $1.1 \times 10^4$ |

**Table 1 Noise Temperature of the Quiet Sun.**

*This assumes the sun's "noise diameter" is 0.5°. The 0.5° value corresponds to a total solid angle of $6 \times 10^{-5}$ steradians; therefore, the noise temperature contribution from the sun is given by*

$$T_S = \frac{6 \times 10^{-5}}{4\pi} \frac{\overline{G} T_{SQ}}{L} \qquad (6)$$

*where $\overline{G}$ is the average level of the antenna pattern toward the sun, and L is the approximate atmospheric attenuation between the sun and antenna which usually can be approximated by the atmospheric loss at low elevation angles.*

*This equation is a reasonable approximation for antennas with beamwidths greater than 1/2 degree. For antennas with beamwidths less than 1/2 degree it would result in a conservative estimate of the sun's contribution to the overall antenna noise temperature.*

**VI. Ground Noise**

*Whenever any part of the antenna pattern points toward the ground, there is a contribution from this source to the antenna noise temperature. This noise is due to blackbody radiation. It can be expressed as*

$$T_G = \frac{\Omega_2 T_G G_2}{4\pi} (1 - \rho^2) \tag{7}$$

*where* $\frac{\Omega_2 G_2}{4\pi}$ *is the weighted total solid angle subtended by the ground.*

*The effective noise temperature of the earth* ($T_G$) *is directly dependent on its capacity to absorb RF energy and its thermal temperature. The earth is generally considered to be at an approximate thermal temperature of 290° K. The effective temperature, however, is dependent on its reflectivity which may vary from nearly unity for smooth water at low grazing angles to nearly zero for rough dry ground at steep angles.*

*The ground noise is a substantial contributor to total antenna temperature especially at low elevation angles where the pattern gain levels on the ground are high.*

**VII. Conclusion**

*A computer program has been written to solve the analytical approximation given in equation 1. The program is arranged to accept actual input pattern data or a more simplified technique of approximating a pattern envelope with mathematical functions. Once the program is equipped with the proper antenna pattern and the necessary input functions, then the high speed digital computer performs the calculation and provides the output data. A typical computer output for a 10 meter antenna at 3.95 GHz is given in Table 2.*

ANTENNA NOISE TEMP. CALCULATION OF 33 FT. ANTENNA

FREQUENCY OF OPERATION (MHZ) ? 3950
GAIN OF ANTENNA (DBI) ? 50.8
GROUND TEMPERATURE (DEGREES KELVIN) ? 290
SURFACE REFLECTION COEFFICIENT (VOLTAGE RATIO) ? 0
TROPOSPHERIC TEMPERATURE (DEGREES KELVIN) ? 290
ATMOSPHERIC LOSS (DB/KM) ? .003
APPROXIMATE TROPOSPHERIC HEIGHT (KM) ? 15
SUN TEMPERATURE (DEGREES KELVIN) ? 55000
AVERAGE LEVEL OF ANTENNA PATTERN TOWARD SUN (DBI) ? 0
ATMOSPHERIC ATTEN. BETWEEN SUN AND ANTENNA (DB) ? .2

---

GAIN OF INPUT PATTERN OR FUNCTION (DBI) = 50.85

| ELEVATION ANGLE | ANTENNA NOISE TEMP |
|---|---|
| 5 | 49.150 |
| 10 | 33.950 |
| 15 | 27.394 |
| 20 | 23.796 |
| 25 | 21.544 |
| 30 | 20.018 |
| 35 | 18.928 |
| 40 | 18.117 |
| 45 | 17.489 |
| 50 | 16.972 |
| 55 | 16.528 |
| 60 | 16.146 |
| 65 | 15.821 |
| 70 | 15.566 |
| 75 | 15.450 |
| 80 | 15.394 |
| 85 | 15.364 |

Table 2. Calculated Antenna Noise Temperature for a 10 Meter Antenna at 3.95 GHz.

*Figure 2 compares the results of the computed noise temperature to actual measured data obtained from a 10 meter antenna at 4 GHz. The agreement between computed and measured temperatures is very good which gives validity to the approximations made in predicting this antenna noise temperature.*

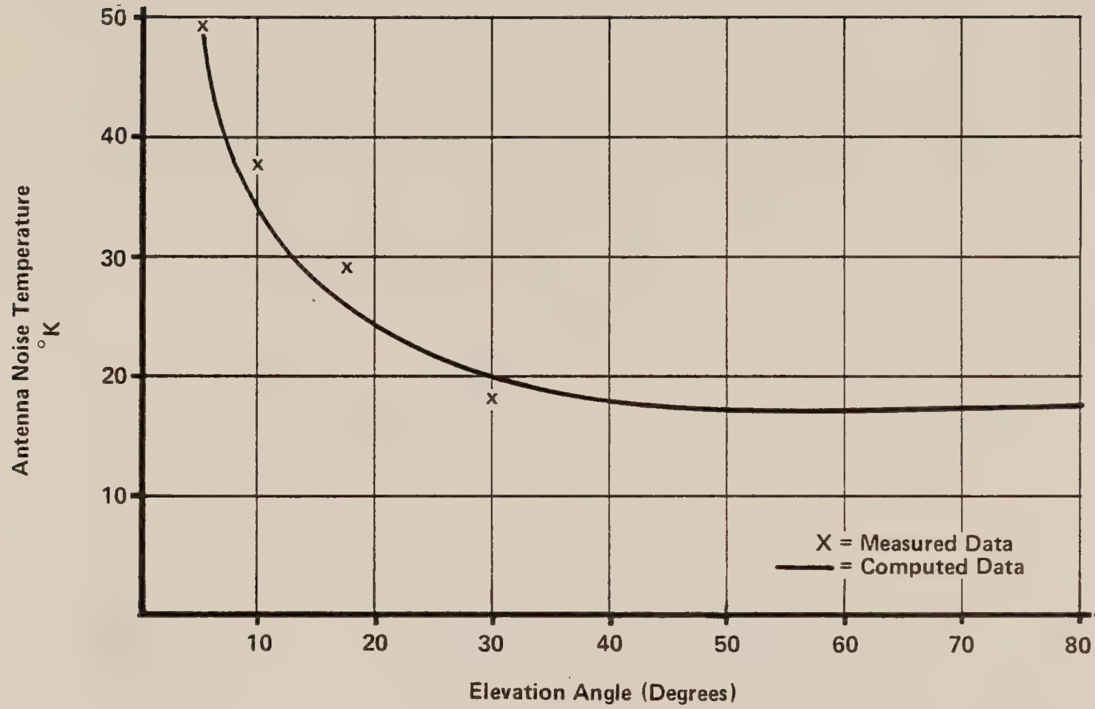



Figure 2. Antenna Noise Temperature vs. Elevation Angle Computed and Measured

*It is obvious from the curve of Figure 2 that the antenna noise temperature could be a large contributing factor to low noise systems, especially at low elevation angles. Therefore, a key factor in accurate prediction of total system noise temperatures is the ability to predict antenna noise.*

References

1. *L.V. Blake, "Antenna and Receiving-System Noise-Temperature Calculation" NRL Report 5668, September 19, 1961.*
2. *D.C. Hogg and W.W. Mumford, "The Effective Noise Temperature of the Sky", The Microwave Journal 3:80-84, March 1960.*
3. *D.C. Hogg and R.A. Semplak, "The Effect of Rain and Water Vapor on Sky Noise at Centimeter Wavelengths", The Bell System Technical Journal: 1331-1348, September 1961.*
4. *H.G. Van De Hulst, "A Course in Radio Astronomy", Leiden Observatory, Leiden, Netherlands, Chap. VI, 1951.*

# GAIN-TO-TEMPERATURE RATIO
# ITS CAUSES and EFFECTS

Marvin Shoemake
Product Line Manager
Satellite Communications Antenna Products

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**I. Introduction** *The required gain-to-noise temperature ratio, often called "G over T" or "Figure of Merit," is almost always mentioned when earth station specifications are discussed. The reason is that G/T is the one parameter that determines what received carrier-to-noise ratio the station will produce for a given incoming wave. This paper provides a brief discussion of what parameters influence the G/T of a system.*

**II. Definitions** *G/T is the ratio of the receive system gain at a specified reference point to the total receive system noise temperature referred to the same reference point. The system gain includes the gains of the antenna and components between the antenna and specified reference point. It should be noted and will be shown by examples that the G/T of a system is independent of the chosen reference point. It is necessary to define a reference point only to ensure that the gain and noise temperature are calculated at the same point in the system.*

*The units of G/T are almost always dB/°K.*

**Example No. 1**

*Consider the hypothetical system of Figure 1. In order to calculate the system G/T we must calculate individually G and T. To do this, we define a reference point at the IF side of the video receiver.*

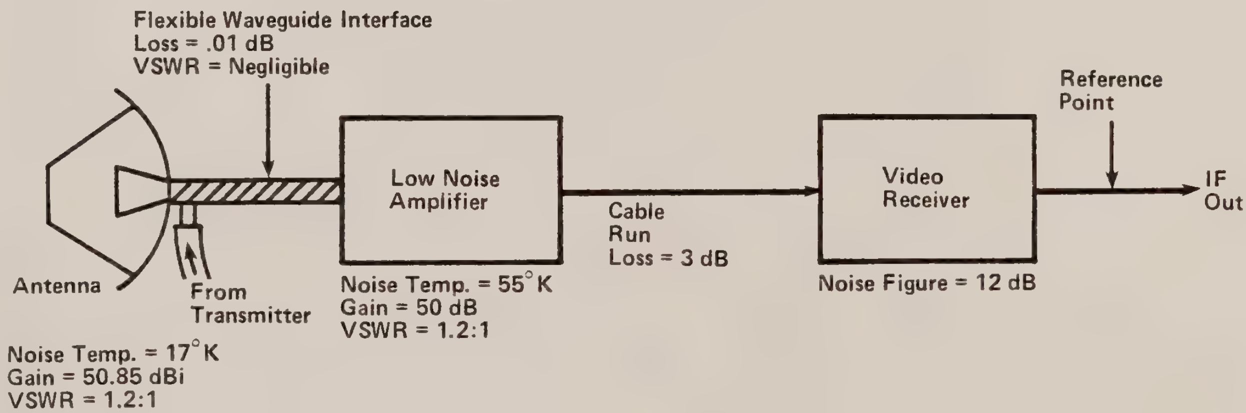



Figure 1

*The gain at the reference point is the total system gain from the antenna to the reference point. In this case*

$$G = 50.85 - .01 - .14 + 50.00 - 3.00 + 0.00 = 97.70 \text{ dB} = 5{,}888{,}436{,}561$$

*The .14 dB arises from the mismatch loss between the antenna and amplifier and represents the worst case loss possible between two VSWR's of 1.2:1 each. The VSWR of the twistguide is negligible, while the VSWR effects behind the LNA are neglected because they are so low with respect to the system gain and noise behind the amplifier.*

*Notice that the gain of the video receiver is here taken as 0 dB.*

*This is because the noise figure (therefore noise temperature) of the receiver is defined at its input for a 0 dB IF signal-to-noise ratio. In other words, the receiver RF to IF gain has been accounted for in defining the receiver noise figure.*

*Now to calculate the system noise temperature at the reference point. To do so, let us first list a few equalities concerning noise temperature:*

*Let Te be the effective noise temperature of a device referred to its input.*
*Let F be the device noise figure, expressed as a power ratio.*
*Let To be the ambient temperature, usually assumed to be 290 °K (17 °C, 63 °F)*

*For a passive device Te = (1-G)To/G*
*For any device Te = (F-1) To*
*The output noise temperature of any device is $T_e \cdot G$.*

*We can find the total system noise temperature by summing the contributions at the reference point from each component. For example, the antenna noise temperature is 17 °K at its terminals. To find its contribution at the reference point we must pass it through the gains of the various components between it and the reference point. Table 1 lists the noise temperature contribution of each component.*

Table 1
Noise Contribution of Each System Component Referenced to the Receiver IF

| Component | Noise Temperature (°K) | Gain Multiplier (dB) | Contribution to Total System Noise (°K) |
|---|---|---|---|
| Antenna | 17.00 | 46.85* | 823,093.02 |
| Twistguide | 0.67 | 46.99 | 33,502.31 |
| LNA | 55.00 | 47.00 | 2,756,529.79 |
| Cable | 291.38 | -3.00 | 146.04 |
| Receiver | 4,306.19 | 0.00 | 4,306.19 |
| Total System Noise Temperature | | | 3,617,577.35 |

Total System Noise in dB is
10 Log (T) = 65.58 dB/°K

**Contains the .14 dB VSWR loss. This VSWR mismatch also adds a slight amount to noise temperature but this contribution is negligible here due to the low loss feed system.*

*The major contributors to the system noise are easily seen to be the components prior to and including the LNA, viz., antenna, twistguide and LNA. This is true in any well-designed earth station.*

*The system G/T is now obvious:*

$$G/T = 5{,}888{,}436{,}561/3{,}617{,}577.35 = 1{,}627$$

*or, in dB:*

$$G/T = 97.70 - 65.58 = 32.12\ dB/^\circ K$$

**Example No. 2**

*Let us now calculate the G/T of the same system but using the input of the LNA as our reference point.*

*The system gain at this point is the sum of the antenna gain, twistguide gain, and mismatch gain.*

$$G = 50.85 - .01 - .14 = 50.70\ dB$$

*The system noise temperature referred to this new point is*

$$T = 72.178\ ^\circ K = 18.58\ dB/^\circ K$$

*as shown by Table 2. The system G/T then is 50.70 – 18.58 = 32.12 dB/°K, and is seen to be independent of the chosen reference point.*

*Notice that the system noise temperature, even when referrenced at the LNA input, includes the contributions of all system components. This may seem incorrect since it is hard to imagine the video receiver producing noise power back at the LNA input. The key to this dilemma is to think of G/T as a parameter which affects IF carrier-to-noise ratio. Referencing G/T to the LNA input is simply a way to keep the mathematics simple, i.e., the noise temperature contributions referenced to this point are small, easily workable numbers.*

*Another point to keep in mind is that noise temperature can be treated simply as any other signal power since noise power is directly proportional to noise temperature.*

*Noise power = KTB where K is Boltzmann's constant and B is system noise bandwidth.*

*Thus, a noise temperature can be referred through a device just like a signal power can be. See Figure 2. Of course the device itself contributes to the noise power so this contribution must be included when using this technique.*

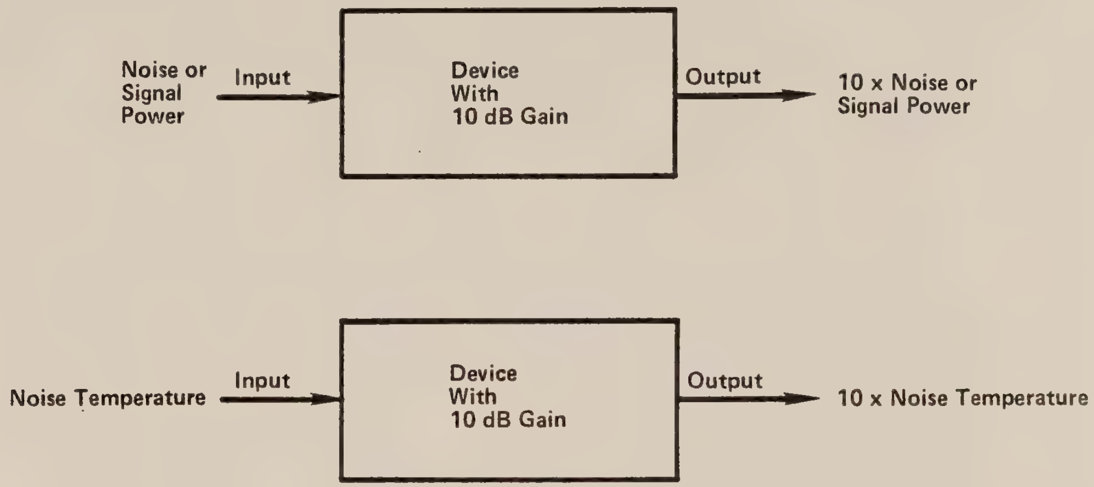



Figure 2

Table 2
Noise Contribution of Each System
Component Referenced to the LNA Input

| Component | Noise Temperature | Gain Multiplier (dB) | Contribution to Total System Noise (°K) |
|---|---|---|---|
| Antenna | 17.00 | -.15 | 16.422 |
| Twistguide | 0.67 | -.01 | 0.667 |
| LNA | 55.00 | 0.00 | 55.000 |
| Cable | 291.38 | -50.00 | 0.003 |
| Receiver | 4,306.19 | -47.00 | 0.086 |
| Total System Noise Temperature | | | 72.178°K |

Total System Noise in dB is
10 Log (T) = 18.58 dB/°K

**Importance of Various Contributors**

*The above calculations show that for the hypothetical system chosen the G/T is critically dependent on the components prior to the LNA. This takes on physical sensibility when we consider that the result of a high G/T is a high signal-to-noise ratio. Since any system component, passive or active, adds noise to the signal it processes, it makes sense that to obtain a maximum S/N we should amplify the signal before processing it through various components. 3 °K of noise temperature, for instance, (yielding an equivalent amount of noise power) does much more harm to the weak signal prior to the LNA than it does to the strong, amplified signal at the LNA output. Thus, maximizing G/T means keeping losses prior to the LNA to a minimum. Components behind the LNA normally have a very small effect. In fact, the receiver and cable in the preceeding example affect the G/T by less than .01 dB/°K.*

**Summary**

*G/T can easily be construed as the single most important RF specification of a receiving system. The fictitious downlink analysis in Table 3 shows that G/T directly affects the system carrier-to-noise ratio, e.g., a 0.1 dB change in G/T means a 0.1 dB change in C/N.*

*The G/T of a system is the same regardless of where in the system it is referrenced and it is critically dependent on losses prior to the LNA.*

Table 3
Fictitious Downlink Analysis Illustrating
Dependency of C/N On G/T

| | |
|---|---|
| Satellite EIRP | 35.00 dBw |
| Satellite Pattern Profile | -2.00 dB |
| Free Space Attenuation (23,000 mile slant range) | -195.90 dB |
| Atmospheric Absorption | -0.20 dB |
| Receive System G/T | 32.12 dB/°K |
| Boltzmann's Constant | +228.60 dB °K/joule |
| System Noise Bandwidth (38 MHz) | -75.80 dB/Hz |
| Received Signal-to-Noise | 21.82 dB |

# ECHO DISTORTION and GROUP DELAY

James H. Cook
Principal Engineer

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

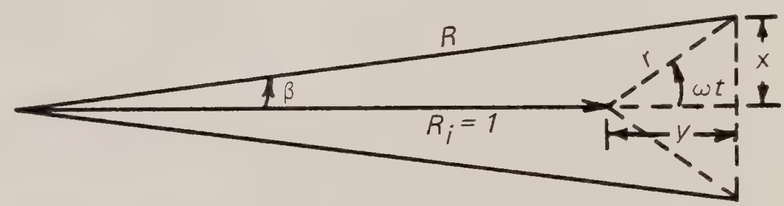
November 8 - 10, 1978

**Echo Distortion and Group Delay**

*An antenna system will be defined as a radiating mechanism consisting of main reflector, sub-reflector, and horn feed and the transmission line consisting of circular waveguide, elliptical waveguide, or rectangular waveguide, as well as any other microwave devices contained in the transmission path between the receiver and the antenna. Echo distortion is defined as that distortion resulting from mismatches in the transmission line or radiating mechanism of the antenna system. It can be caused by discontinuities within the waveguide, mismatches of microwave components, and the mismatch of the horn and/or reflectors. The distortion results from a second signal (or multiple signals) arriving at the receiver but delayed in time with respect to the desired signal. The echo will be constant since the mismatch which established it is constant. Therefore, the distortion created by the echo will be constant but is contingent upon modulation. Of course, echo distortion will only appear when the carrier is modulated.*

**Derivation of Envelope Delay**

*It can be shown that an echo signal causes the carrier phase to change sinusoidally with frequency.*




*The figure above shows the vector relationship between the carrier ($R_i$) and the echo signal at a given frequency within the system passband with an echo signal at a given frequency within the system passband with an echo delay time of t seconds. Maximum phase shift occurs when*

$$\omega = \pi/2 \text{ or } 3\pi/2 \text{ radians}$$

*Maximum envelope delay will occur when*

$$\omega = 0 \text{ or } \pi \text{ radians}$$

*From the figure above*

$$x = r(\sin \omega t) \qquad \tan \beta = \frac{r(\sin \omega t)}{R_i + r(\cos \omega t)}$$

$$y = r(\cos \omega t)$$

*Assuming $R_i = 1$,*

$$\tan \beta = \frac{r(\sin \omega t)}{1 + r(\cos \omega t)}$$

$$\therefore \beta = \tan^{-1}\left(\frac{r(\sin \omega t)}{1 + r(\cos \omega t)}\right)$$

$$\text{Let } u = \frac{r(\sin \omega t)}{1 + r(\cos \omega t)}$$

$$\text{then } \beta = \tan^{-1}(u)$$

$$\text{and } \frac{d}{du}(\tan^{-1}(u)) = \frac{1}{1 + u^2}$$

$$\text{or} \frac{d}{du}(\tan^{-1}(u)) = \frac{1}{\dfrac{r^2 \sin^2 \omega t}{(1 + r(\cos \omega t)^2} + 1}$$

$$= \frac{1 + 2\,r(\cos \omega t) + r^2 \cos^2 \omega t}{1 + 2\,r(\cos \omega t) + r^2}$$

*For peak envelope delay, $\omega t = 0$*

$$\therefore \frac{d}{du}(\beta) = \frac{1 + 2r + r^2}{1 + 2r + r^2} = 1$$

$$\text{Now} \frac{du}{d\omega} = \frac{(1 + r(\cos \omega t)\, rt\,(\cos \omega t) - r(\sin \omega t)\ \ (-rt\,(\sin \omega t))}{(1 + r(\cos \omega t))^2}$$

*For peak envelope delay*

$$\frac{du}{d\omega} = \frac{(1 + r)\,rt}{(1 + r)^2} = \frac{rt}{1 + r}$$

Now the value of $\frac{d\beta}{d\omega} = \frac{du}{d\omega} \cdot \frac{d\beta}{du}$

$$\frac{d\beta}{d\omega} = \frac{rt}{1 + r}$$

As the carrier phase shift is both positive and negative, the envelope delay peak-to-peak value is

$$|\text{Envelope Delay}| = 2 \frac{d\beta}{d\omega}$$

Since $r << 1$, the envelope delay can be approximated by

$$\text{Envelope Delay} \doteq 2\, rt$$

It is evident that either r, the reflection coefficient, or t, the time delay which is dependent on separation between discontinuities must be an appreciable magnitude to cause an envelope delay that would need compensation.

Considerable information is available in literature on the echo distortion effects of waveguide and waveguide components. An important contributor which is sometimes neglected is the interaction between the subreflector and in the antenna system. Typical values are .08 (1.17:1 VSWR) for the feed and .07 (1.15:1 VSWR) for the subreflector. These correspond to 21.94 dB and 23.10 dB return losses, respectively. Since the distortion is produced by the reflected signal between the two mismatch its magnitude r is calculated as follows:

$$r = \text{anti} \log_{10} \left( \frac{RL + RL_2}{20} \right)$$

For this example r = .0056 if we assume that the loss factor between the two reflection points is very small. The delay per foot in free space is 1.016 nanosec/ft or $1.016 \times 10^{-9}$ sec/ft.

The distance between the feed and the subreflector is typically on the order of 10 feet for a 10 meter reflector and 50 feet for a 30 meter reflector. The time delay is given by 2 delay/ft x distance (ft) where the 2 factor is a result of the two-way path between the discontinuities. For the two reflector sizes above the time delays are 20.32 nanosec and 101.6 nanosec.

*The envelope delay for these two cases can now be easily calculated.*

$$\text{Envelope Delay} \doteq 2rt$$

$$\underline{\text{10 Meter}} \quad \text{E.D.} = 2\,(.0056)\ \ (20.32\ \text{nanosec})$$
$$= .228\ \text{nanosec}$$

*The period of the envelope delay ripple is*

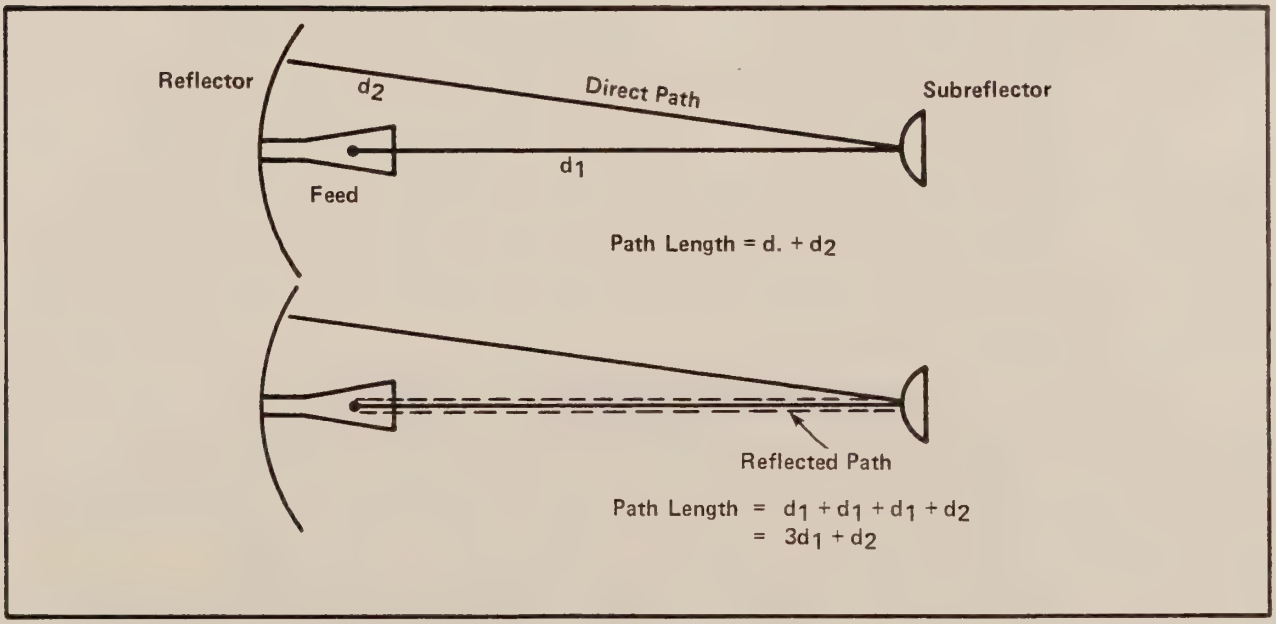
$$\text{Period} = \frac{1\ \text{Hz}}{\text{Delay Time}}$$

$$\text{Period} = 1\ \text{Hz}/20.32 \times 10^{-9}$$
$$= 49.21\ \text{MHz}$$

$$\underline{\text{30 Meter}} \quad \text{E.D.} = 2(.0056)\ \ (101.6\ \text{nanosec})$$
$$= 1.138\ \text{nanosec}$$
$$\text{Period} = 1/101.6 \times 10^{-9}$$
$$= 9.843\ \text{MHz}$$

*As can be seen the envelope delay for a 10 meter antenna is of a magnitude that it should be considered in the overall compensation of the antenna system. The delay for a 30 meter antenna is of such a magnitude that would make it unacceptable in operation. In order to minimize the envelope delay for the 30 meter antenna it would be necessary to tune the subreflector by the use of a vertex matching section. This technique has been used by AT&T. After adjusting the vertex plate they were successful in reducing the mismatch of the subreflector to 1.02:1 or 40 dB return loss. This reduces the envelope delay to:*

$$\text{Envelope Delay} = 2\,(.008)\ \ (101.6\ \text{nanosec})$$
$$= .162\ \text{nanosec}$$



# ADJACENT CHANNEL INTERFERENCE

James H. Cook
Principal Engineer

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## ADJACENT CHANNEL INTERFERENCE

*For operation in a frequency reuse system there are 24 transponder channels. If every channel carries traffic, for any one channel, the remaining 23 channels act as interference. However, only the four nearest channels in frequency cause an appreciable interference. These four channels consist of the two co-polarized adjacent channels and the two cross-polarized adjacent channels.*

*Co-polarized: Two channels whose center frequencies are 40 MHz above and below the center frequency of the desired channel reduced in amplitude by the suppression of the input and output MUX filters.*

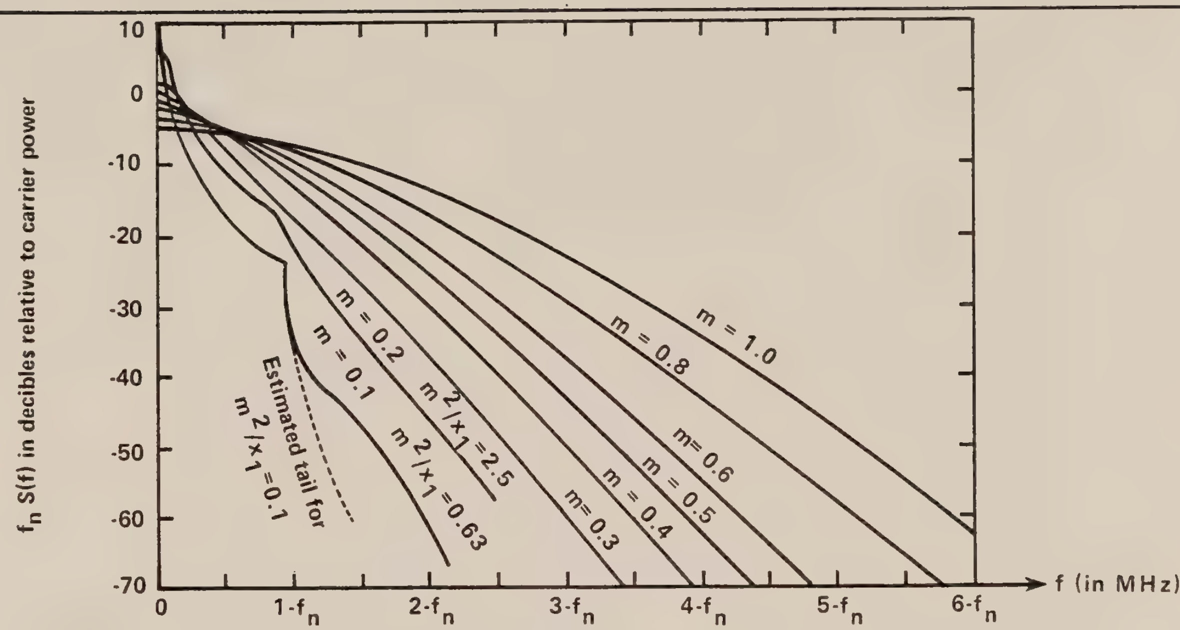
*Cross-polarized: Two channels whose center frequencies are 20 MHz above and below the center frequency of the desired channel, reduced in amplitude by the cross-polarization discrimination and to some extent by the suppression and shaping of the input and output MUX filters.*

*It is assumed that all the interferences are incoherent. The amount of interference can be computed by convolving the power spectra of the wanted and unwanted signals. Therefore, the power spectra of each signal must be described to calculate the carrier-to-interference ratios.*

### Power Spectra of a FDM-FM Carrier

*The spectrum of a carrier that is frequency modulated by a multiplexed telephony baseband is, in general, a complicated function which depends on many parameters. When the baseband signal consists of many single-sideband, frequency-multiplexed telephone channels, it is often convenient to simulate the baseband signal by an equivalent band of random noise. The determination of the power spectrum when the modulating signal consists of random noise involves considerable analysis. A particular case, often assumed in the analysis of a radio system is that of FM by a random noise signal of uniform power density. (Proc. IEEE, Part B, Vol. 108, pp 75-89, Jan. 61). The shape of the power spectrum in this case largely depends on the modulation index (rms modulation index is useful since the modulating signal is a random noise voltage).*

*When the rms modulation index is very small and the lowest modulation frequency is not zero as arises in practice, a bounded continuous spectrum results, together with a residual carrier at the mean carrier frequency as shown in Figure 1 (the case of $m = 0.1$, $m^2/x_1 = 0.1$, $x_1 = f_1/f_n$). The residual carrier corresponds to the carrier component of the spectrum when a single modulating tone is used and the ratio of $f_1/f_n$ is that of the lowest to the highest modulating frequency.*




$f_n$: Highest modulating frequency in MHz
S(f): Power spectrum in dB/MHz
m: Multichannel RMS deviation
x: $f/f_n$

Figure 1. Power spectrum of a FDM-FM carrier for RMS modulation index m = 0.1 ~ 1.0.$S(f)f_n$ expressed in dB relative to unmodulated carrier power (normalized for unit carrier power).

*For intermediate values of rms modulating index, power spectra based on measurements are believed to be the most reliable. Normalized spectrum curves obtained from measurements are shown in Figure 1 for eight values of m between 0.1 and 1.0.*

*When the rms modulation index is larger (>1.5) the mean power spectrum normalized for unit carrier power is of the form:*

$$S_\phi(f) = \frac{1}{\sqrt{2\pi}\,\sigma} \; e^{-f^2/2\sigma^2}$$

*where*

$\sigma$ = *multichannel rms deviation in MHz*
$f$ = *frequency relative to carrier frequency in MHz*
$\phi(t)$ = *multiplexed telephone baseband signal, simulated by a random noise signal of uniform power spectra.*

*Figure 2 shows the power spectrum when rms deviation is 4 MHz. In order for rms modulation index, m, to be greater than 1.5, the highest modulation frequency has to be less than 2.96 MHz resulting in Carson's bandwidth of 34 MHz. In this case 705 voice channels can be multiplexed.*

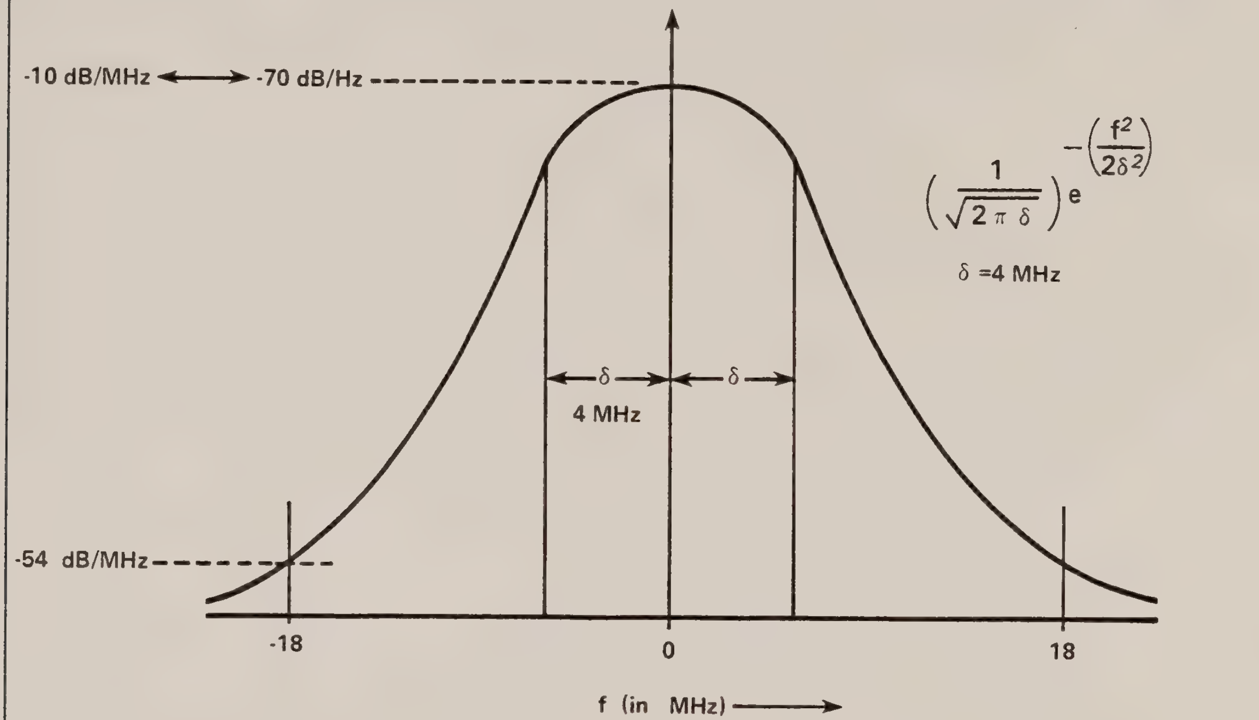



Figure 2. Power spectrum of a FDM-FM carrier when RMS modulation index is large.

**Power Spectrum of a TV/FM Carrier**

*According to H.W. Evans, Bell Laboratories, the power in any 4 kHz band is at least 30 dB below (i.e., 66 dB/Hz) the power of the unmodulated carrier when the peak frequency deviation ratio is 3, using Bell System standard pre-emphasis. These calculations assumed the FM spectrum of a band of white noise is similar to the spectra of pre-emphasized FM TV signals near the carrier where the density is highest.*

*According to the power spectra shown on page 461 of Bell Laboratories "Transmission Systems for Communication", the power spectra is almost flat over the bandwidth of 2 $f_T$ and drops outside of this range with the rate of change dependent upon the rms phase deviation. The power spectral shape reported by COMSAT is similar. It is flat over ±12.5 MHz from the carrier and*

$$B_{IF} = 2(\Delta f_1 + f_m)$$

$$= 2(12.5 + 5.5) = 36 \text{ MHz}$$

*If we assume most of the power is contained in this 25 MHz band at this frequency deviation, the power in any 1 MHz band is 15 dB below the power of the unmodulated carrier (10 log (1/25) = -14 dB). See Figures 3 and 4.*

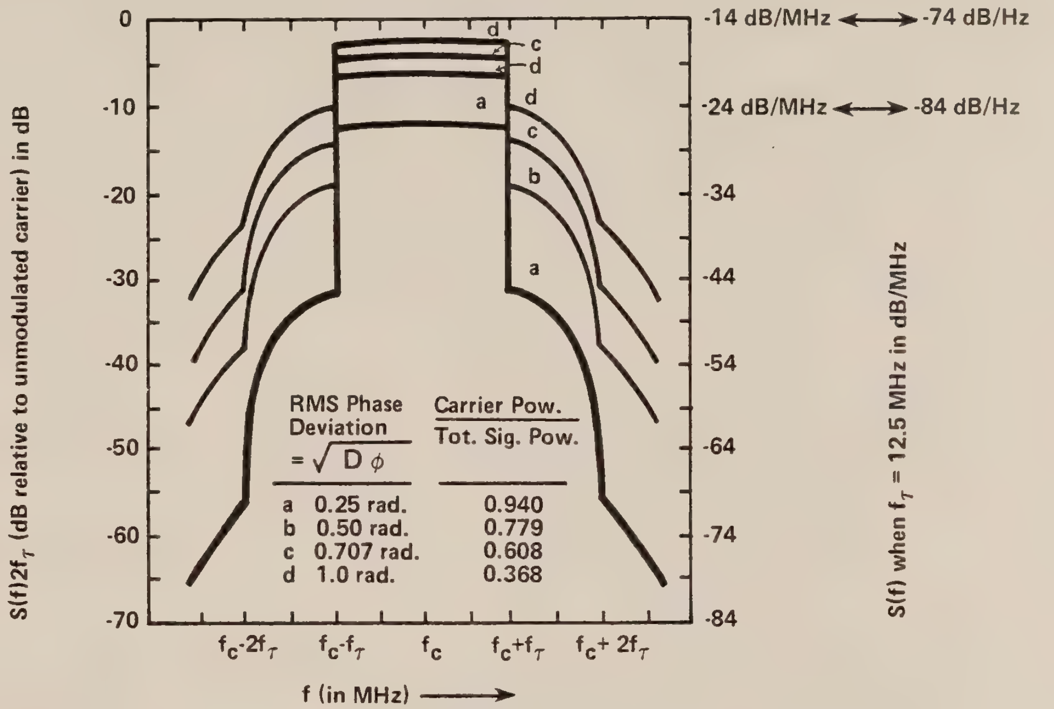



Figure 3. Sideband spectra of a carrier phase-modulated by a baseband signal consisting of a flat band of random noise which extends from 0 to $f_T$ Hz.

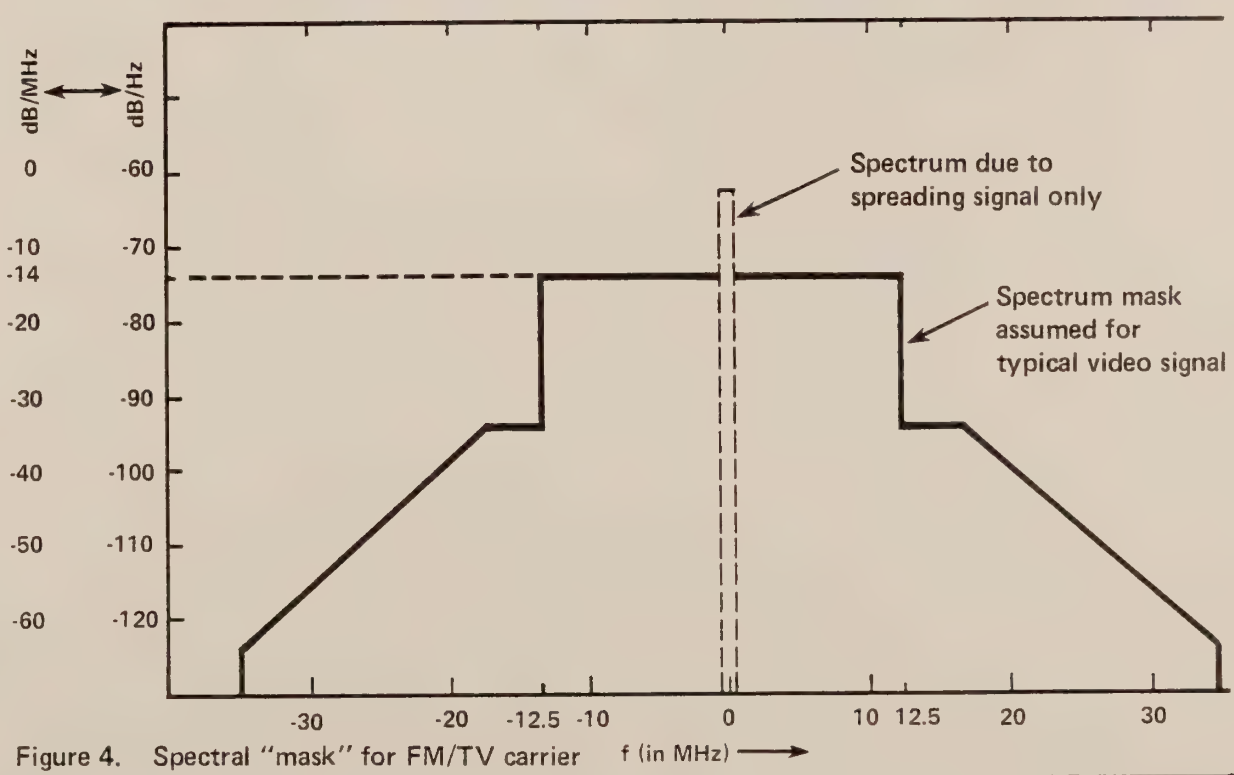



Figure 4. Spectral "mask" for FM/TV carrier

*Figure 5 shows power spectrum used in this analysis.*

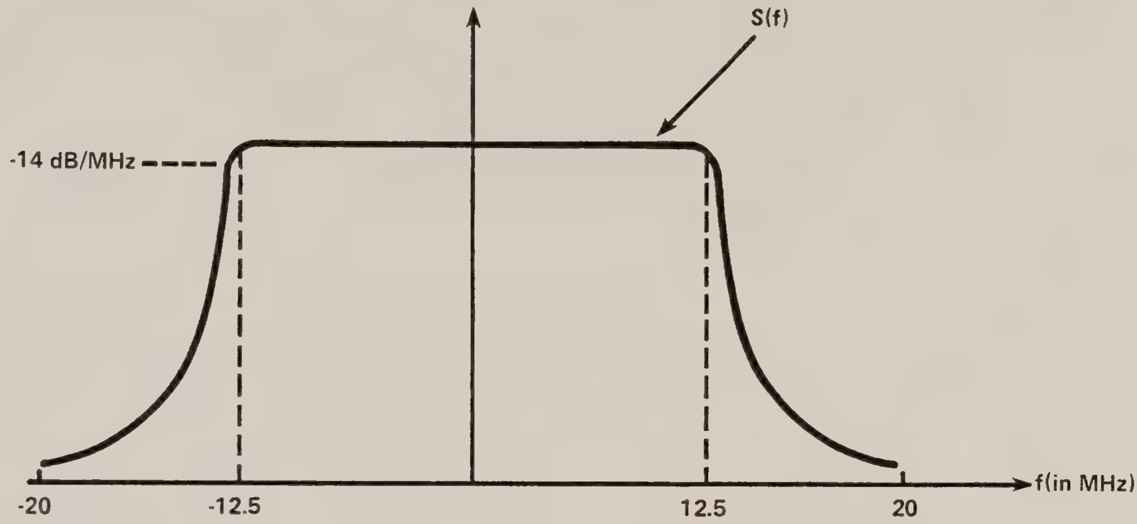



Figure 5. Approximate power spectrum of a FM/TV carrier used for the analysis.

Power Spectrum of a $4\phi$-PSK Carrier (High Bit Rate Data)

*The primary cause of adjacent channel interference from PSK carriers is the power spectrum spreading due to TWT non-linearities. Power spectrum spreading is discussed extensively by Lyons, "Effects of PSK Spectral Spreading in a Satellite Transponder," IEEE International Comm. Conf. pp 363-1, June 1974 and will not be discussed here.*

*The power structure shown in Figure 6 below will be used for this analysis.*

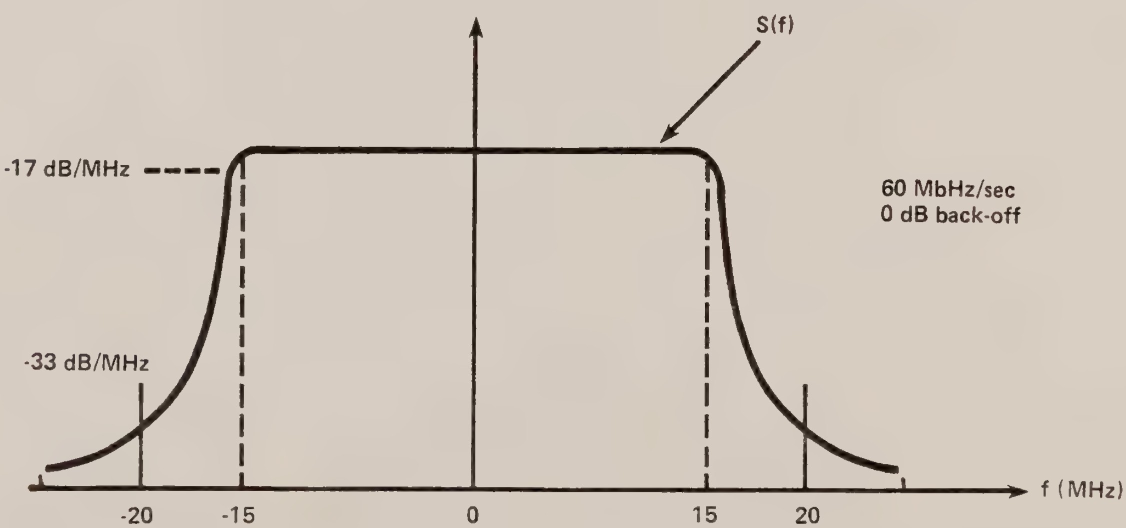



Figure 6. Approximate Power Spectrum of a $4\phi$-PSK Carrier (High Bit Rate Data)

**Power Spectrum of SCPS Carriers and Associated Intermod**

*The primary interference of SCPC carriers is due to the carriers themselves and not to the associated intermod power spectrum. Theoretical investigation has shown that the intermod spectrum peak is 16 below the carrier level and therefore will be neglected in this analysis.*

**Interference to a FM/TV Channel**

*Let I denote the interfering power without taking the cross-polarization isolation into consideration, expressed in dB below saturation.*

$$I = 10 \log (S(f_1) + 10 \log (B), \text{ dB below saturation}$$

*where*

$S(f_1)$ = *power spectral density at* $f_1$ *(MHz)*

$f_1$ = *frequency from the center of the power spectrum of an interfering signal to the FM/TV carrier*

$B$ = *RF noise bandwidth associated with a FM/TV carrier (MHz)*

*For FDM/FM-Co-Polarized*

$$I = 10 \log \left[ \frac{1}{\sqrt{(2\pi)(16)}} e^{-40^2/(2 \times 4^2)} \right] + 10 \log (B)$$

$$= 10 \log \left[ 1.9339 \times 10^{-21} \right] + 10 \log B$$

$$= -207 \qquad +10 \log B$$

$$= \text{negligible}$$

*For HBR Data*

$$I = -17 \text{ dB/MHz} + 10 \log B$$

$$I = \frac{-17 \text{ dB}}{\text{MHz}} .25 \text{ MHz} + 10 \log B$$

$$= -425 + 10 \log B$$

$$= \text{negligible}$$

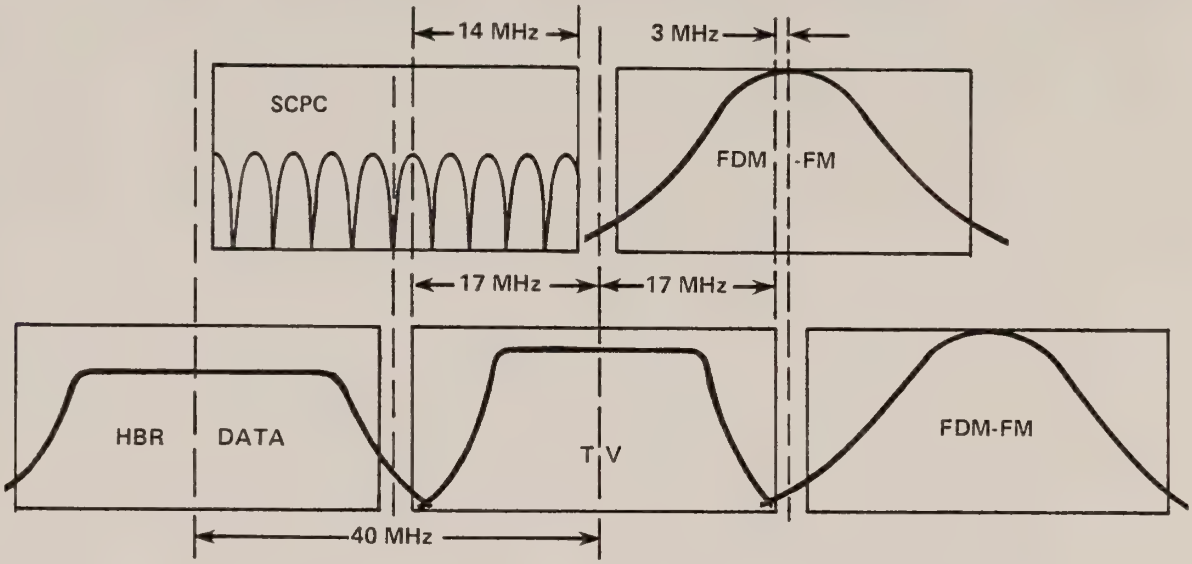



Figure 7. Interference Model to a TV Channel for Typical Reuse Satellite

*FDM-FM Cross-Polarized*

$$I = 10 \log \left[ \int_{-\infty}^{-3} \frac{1}{\sqrt{2\pi}\,\sigma} e^{\frac{-f^2}{2\sigma^2}} df \right]$$

$\sigma = 4$ MHz

$I = 10 \log (0.2266)$

$= -6.45$ dB below saturation

*SCPC Cross-Polarized*
*By assuming that SCPC carriers in 14 MHz band (17 MHz - 3 MHz) are directly interfering with FM/TV channel, the interfering power will be:*

$I = 10 \log$ (14 MHz/34 MHz)

$= -3.9$ dB below saturation

*C/I Due to Cross-Polarized FDM/FM Channel*
*For the offset cross-polarized FDM/FM channel, the interfering power I is -6.45 dB below saturation. This means that the interfering power into the FM/TV channel on the uplink is*

$$P_I = -81.5 \text{ dBw/m}^2 + (-37 \text{ dB-m}^2) + G_{sat} - 6.45 - (XPD)_U$$

*The power of the FM/TV carrier on the uplink is*

$$P_c = -81.5 \text{ dBw/m}^2 + (-37 \text{ dBm}^2) + G_{sat}$$

*saturation flux density* $= -81.5$ dBw/m$^2$

*effective area of isotropic* $= -37$ dBm$^2$

*$\therefore$, carrier to interference ratio on the uplink is*

$$\left(\frac{C}{I}\right)_U = 6.45 + (XPD)_U$$

*where XPD is the cross polarization discrimination*

*For the downlink, the interfering power is*

$$P_I = 32\ dBw - \text{Path loss} + G_{E.S.} - 6.45 - (XPD)_D$$

*The FM/TV carrier power on the downlink is*

$$P_C = 32\ dBw - \text{Path Loss} + G_{E.S.}$$

*$\therefore$ carrier to interference ratio on the downlink is*

$$\left(\frac{C}{I}\right)_D = 6.45 + (XPD)_D$$

*Then, the total carrier to interference ratio will be*

$$\frac{C}{I} = \left(\frac{C}{I}\right)_U \boxed{+} \left(\frac{C}{I}\right)_D$$

$$= \left\{6.45 + (XPD)_U\right\} \boxed{+} \left\{6.45 + (XPD)_D\right\}$$

*where*

$\boxed{+}$ *denotes power summation*

*C/I Due to Cross-Polarized SCPC Channel*

*For the offset cross-polarized SCPC channel, the interfering power, I is -3.9 dB below saturation. This means that the interfering power into the FM/TV channel on the uplink is*

$$P_I = (-81.5\ dBW/M^2 - \text{input back off}) + (-37\ dBm^2) + G_{sat}$$
$$-3.9 - (XPD)_U$$

*The power of the FM/TV carrier on the uplink is*

$$P_C = -81.5\ dBw/m^2 + (-37\ dBm^2) + G_{sat}$$

$$\therefore \left(\frac{C}{I}\right)_U = +3.9 + \text{input back-off} + (XPD)_U$$

*Typically input back-off = 4 dB*

$$\left(\frac{C}{I}\right)_U = +7.9 + (XPD)_U$$

*On the downlink, the interfering power is*

$$P_I = (32\ \text{dBw - output back-off}) - \text{Path loss} + G_{E.S.} - 3.9 - (XPD)_D$$

*and the power of the FM/TV carrier is*

$$P_C = 32\ \text{dBw} - \text{Path loss} + G_{E.S.}$$

$$\therefore \left(\frac{C}{I}\right)_D = 3.9 + \text{output back-off} + (XPD)_D$$

*Output back-off = 2.6*

$$\left(\frac{C}{I}\right)_D = 6.5 + (XPD)_D$$

*Total carrier to interference ratio will be*

$$\left(\frac{C}{I}\right) = \left\{7.9 + (XPD)_U\right\} \left|\frac{+}{}\right| \left\{6.5 + (XPD)_D\right\}$$

*Total C/I For System*

$$\left(\frac{C}{I}\right)_S = \left\{\frac{C}{I}\right\}_{FDM/FM} \left|\frac{+}{}\right| \left\{\frac{C}{I}\right\}_{SCPC}$$

**Polarization; Typical Site Central United States**

I. Up Link

| | | |
|---|---|---|
| *Satellite* | *35 dB* | |
| *Ground Station* | *35 dB* | *28.0 dB* |
| *Faraday* | *35 dB* | |

II. Down Link

| | | |
|---|---|---|
| *Satellite* | *35 dB* | |
| *Ground Station* | *35 dB* | *26.0 dB* |
| *Faraday* | *29 dB* | |

III. Atmospheric Effect - 25° Elevation Angle

| % Time | Rain Rate | 4 GHz | 6 GHz |
|---|---|---|---|
| *99.0* | *1/2″/hr* | *33.0* | *30.5* |
| *99.9* | *1-1/2″/hr* | *25.0* | *21.0* |
| *99.99* | *3″/hr* | *20.0* | *16.5* |

IV. Cross-Polarization Discrimination

| % Time | 4 GHz | 6 GHz |
|---|---|---|
| *99.0* | *22.8* | *23.1* |
| *99.9* | *19.5* | *17.8* |
| *99.99* | *16.5* | *14.5* |

V. Carrier-To-Interference TV/FM

| % Time | $(XPD)_u$ | $(XPD)_D$ | $(C/I)_u$ | $(C/I)_D$ | $(C/I)_S$ |
|---|---|---|---|---|---|
| *99.0* | *23.1* | *22.8* | *27.10* | *26.56* | *23.81* |
| *99.9* | *17.8* | *19.5* | *21.2* | *21.26* | *18.22* |
| *99.99* | *14.5* | *16.5* | *18.6* | *17.96* | *15.26* |

*A more thorough examination of this subject is contained in a RCA American Communications transmission engineering report prepared by Dr. M.K. Lee. This report is entitled, "Overall System Cross-Polarization Isolation and Interference from Cross-Polarized Channels in the Spectrum Reuse System", Report No. TER-008-75. The discussion and analysis of this paper contains concepts and details that are presented in this report. Appreciation is noted for Dr. Lee's work.*

# FREQUENCY REUSE – CROSS-POLARIZATION DISCRIMINATION AND FEED COMPONENTS

Sharad Parekh, Ph. D.
Senior Engineer
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Introduction**

The term "frequency reuse" is a modern concept in satellite communication where the use of the available communication channel bandwidth is made more efficient by transmitting and/or receiving dual orthogonal polarized signals. This system makes use of the polarization state of an electromagnetic field to allow two independent signals to be sent through the same communication link at the same frequency. Assuming the two carriers are orthogonal then there will be no interaction between the two signals at the receiving end. Unfortunately, imperfections in the propagating medium do not allow the signals to remain orthogonal and interaction between the two signals imposes a certain limitation on the purity of these signals. To reduce the level of interference to a certain desired degree, adjustable mechanisms can be implemented in the feed circuitry. In this paper we shall discuss the factors that limit the polarization purity of the signals and present some typical calculated values of the isolation between the orthogonal signals. Further, we shall discuss types of feeds and mechanisms available to compensate for the depolarization and present some practical cases.

Although one can refer with commonality to either linear or circular polarization, we shall essentially deal with linear polarization. For domestic applications the latter is of concern only. The interference between orthogonal signals in the same frequency band is denoted by the term "cross-polarization discrimination (XPD)" and is usually expressed in decibels. The higher the XPD, the less the interference and vice versa.

**Depolarization Factors**

Several important factors which affect the XPD in a frequency reuse system are:

a. Depolarization due to ionosphere
b. Depolarization due to rain
c. Cross-polarization of the satellite antenna system
d. Cross-polarization of the earth station antenna
e. Angular misalignment between satellite and earth station antennas
f. Misalignment of the antenna polarization vectors

Factors "e" and "f" are assumed to have a negligible effect for the present purpose. Factors "c" and "d" can be controlled by proper design tools and precision manufacturing.

The latter two factors are fixed quantities and are assumed to be time invariant. The first factor (i.e., "a") is considered for most practical purposes to be a predictable time variant factor and the second factor is also time variant based on a percentage of time. We shall, briefly, discuss the first two factors and present some typical data.

**Depolarization Due to Ionosphere**

The ionospheric effect on linearly polarized signals is known as the "Faraday Effect". The effect rotates an incident signal in the transverse plane by a certain angle $\Omega$ degrees. For details of the physical mechanism involved, one should refer to an excellent report * by M.K. Lee of RCA. The rotation is esentially dependent on time and has approximately a sinusoidal variation dependence as a function of diurnal, seasonal and yearly (solar cycle period) periods. Tables 1 and 2 (taken from Lee) show the maximum daytime and minimum nighttime rotation angles for different seasons during the minimum sunspot (R=0) and maximum sunspot (R=100) activity periods. These tables refer to 4 and 6 GHz bands.

*M.K. Lee, "Depolarization Effect Due to Faraday Rotation in the Spectrum Reuse System", RCA Report TER-005-75, RCA Globcom, Inc., N.J., 1975.

The XPD resulting from the above rotation is given by:

$$XPD = 20 \log \sin(\Omega) \text{ dB} \tag{1}$$

Based on this equation, the XPD corresponding to the values in Tables 1 and 2 is shown in Tables 3 and 4. It can be observed that as $\Omega$ increases, the XPD decreases.

| | R / Ω | R = 0 | | | | R = 100 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Daytime Max. | | Nighttime Min. | | Daytime Max. | | Nighttime Min. | |
| | Station | Mean | 20% above Mean | Mean | 20% above Mean | Mean | 20% above Mean | Mean | 20% above Mean |
| Spring | Houston | 0.74 | 0.89 | 0.15 | 0.18 | 2.04 | 2.45 | 0.28 | 0.34 |
| | Average over 48 states | 0.61 | 0.73 | 0.14 | 0.17 | 1.83 | 2.20 | 0.27 | 0.32 |
| | Juneau | 0.24 | 0.29 | 0.05 | 0.06 | 1.31 | 1.57 | 0.15 | 0.18 |
| | Hawaii | 0.87 | 1.04 | 0.07 | 0.08 | 1.72 | 2.06 | 0.12 | 0.14 |
| Summer | Houston | 0.59 | 0.71 | 0.17 | 0.20 | 1.23 | 1.48 | 0.34 | 0.41 |
| | Average over 48 states | 0.50 | 0.60 | 0.18 | 0.22 | 1.05 | 1.26 | 0.31 | 0.37 |
| | Juneau | 0.47 | 0.56 | 0.22 | 0.26 | 0.87 | 1.04 | 0.33 | 0.40 |
| | Hawaii | 0.62 | 0.74 | 0.09 | 0.11 | 1.24 | 1.49 | 0.20 | 0.24 |
| Winter | Chicago | 0.66 | 0.79 | 0.07 | 0.08 | 2.15 | 2.58 | 0.23 | 0.28 |
| | Average over 48 states | 0.60 | 0.72 | 0.07 | 0.08 | 1.88 | 2.26 | 0.16 | 0.19 |
| | Juneau | 0.49 | 0.59 | 0.02 | 1.77 | 2.12 | 0.07 | 0.08 | |
| | Hawaii | 0.58 | 0.70 | 0.06 | 0.07 | 1.26 | 1.51 | 0.09 | 0.11 |

Table 1. Faraday Rotation Angles at 4 GHz.

| | R / Ω | R = 0 | | | | R = 100 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Daytime Max. | | Nighttime Min. | | Daytime Max. | | Nighttime Min. | |
| | Station | Mean | 20% above Mean | Mean | 20% above Mean | Mean | 20% above Mean | Mean | 20% above Mean |
| Spring | Houston | 0.33 | 0.40 | 0.07 | 0.08 | 0.91 | 1.09 | 0.13 | 0.16 |
| | Average over 48 states | 0.27 | 0.32 | 0.06 | 0.07 | 0.81 | 0.97 | 0.12 | 0.14 |
| | Juneau | 0.19 | 0.23 | 0.02 | 0.02 | 0.58 | 0.70 | 0.07 | 0.08 |
| | Hawaii | 0.38 | 0.46 | 0.03 | 0.04 | 0.76 | 0.91 | 0.06 | 0.07 |
| Summer | Houston | 0.26 | 0.31 | 0.08 | 0.10 | 0.55 | 0.66 | 0.15 | 0.18 |
| | Average over 48 states | 0.22 | 0.26 | 0.08 | 0.10 | 0.47 | 0.56 | 0.14 | 0.17 |
| | Juneau | 0.21 | 0.25 | 0.10 | 0.12 | 0.39 | 0.47 | 0.15 | 0.18 |
| | Hawaii | 0.28 | 0.34 | 0.04 | 0.05 | 0.55 | 0.66 | 0.09 | 0.11 |
| Winter | Chicago | 0.30 | 0.36 | 0.03 | 0.04 | 0.95 | 1.14 | 0.06 | 0.07 |
| | Average over 48 states | 0.27 | 0.32 | 0.04 | 0.05 | 0.83 | 1.00 | 0.07 | 0.08 |
| | Juneau | 0.22 | 0.26 | 0.01 | 0.01 | 0.79 | 0.95 | 0.03 | 0.04 |
| | Hawaii | 0.26 | 0.31 | 0.03 | 0.04 | 0.56 | 0.67 | 0.04 | 0.05 |

Table 2. Faraday Rotation Angles at 6 GHz.

**Depolarization Due to Rain**

This effect is caused essentially by:

a. Non-spherical nature of the rain drops
b. Geometrical orientation of the rain drop with respect to the incoming field vector of a given polarization.

The latter is commonly referred to as the canting angle effect and, in general, a distribution of canting angles has to be assumed. Such an assumption involves complex calculations of the XPD. Another report by M.K. Lee (RCA Report TER-001-75, 1975) has treated in detail the XPD due to rain.

In essence, the non-spherical nature of the rain drop introduces a differential phase and differential attenuation effect which give a degradation in XPD. For the 4 and 6 GHz bands the differential attenuation effect is negligible whereas, in heavy rainfall areas, the differential phase effect can degrade the XPD quite substantially. The effect of rain is esentially measured on a percentage of time basis. Tables 5 and 6 show the XPD as a function of rate of rainfall for different site elevation angles. Note, we have assumed a constant canting angle for each three canting angles considered. It should be noted that the effects due to rain are directly proportional to frequency, and as such the expected XPD in the 6 GHz band is much worse compared to the 4 GHz band.

Briefly, the linearly polarized signal suffers distortion through the rain in the sense that the signal becomes elliptically polarized.

| | R / xpi (dB) / Station | R = 0 | | | | R = 100 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Daytime Min. | | Nighttime Max. | | Daytime Max. | | Nighttime Max. | |
| | | Mean | 20% above Mean | Mean | 20% above Mean | Mean | 20% above Mean | Mean | 20% above Mean |
| Spring | Houston | 37.8 | 36.2 | 51.6 | 50.1 | 29.0 | 27.4 | 46.2 | 44.5 |
| | Average over 48 states | 39.5 | 45.9 | 61.2 | 59.6 | 32.8 | 31.2 | 51.6 | 50.1 |
| | Juneau | 47.6 | 37.8 | 58.3 | 57.1 | 30.5 | 28.9 | 53.6 | 52.2 |
| Summer | Houston | 39.7 | 38.1 | 50.6 | 49.1 | 33.4 | 31.8 | 44.5 | 42.9 |
| | Average over 48 states | 41.2 | 39.6 | 50.1 | 48.3 | 34.7 | 33.2 | 45.3 | 43.8 |
| | Juneau | 41.7 | 40.2 | 48.3 | 46.9 | 36.4 | 34.8 | 44.8 | 43.1 |
| | Hawaii | 39.3 | 37.8 | 56.1 | 54.3 | 33.3 | 31.7 | 49.1 | 47.6 |
| Winter | Chicago | 38.8 | 37.2 | 58.3 | 57.1 | 28.5 | 26.9 | 47.9 | 46.2 |
| | Average over 48 states | 39.6 | 38.0 | 58.3 | 57.1 | 29.7 | 28.1 | 51.1 | 49.6 |
| | Juneau | 41.4 | 39.7 | 69.1 | 69.1 | 30.2 | 28.6 | 58.3 | 57.1 |
| | Hawaii | 39.9 | 38.3 | 59.6 | 58.3 | 33.2 | 31.6 | 56.1 | 54.3 |

Houston ——— Yields largest value of Daytime Max. among 48 states in spring & summer.
Chicago ——— Largest value of Daytime Max. among 48 states in winter.

Table 3. Cross-Polarization Discrimination Due to Faraday Rotation at 4 GHz (dB).

| Season | Station | R = 0 Daytime Min. Mean | R = 0 Daytime Min. 20% above Mean | R = 0 Nighttime Max. Mean | R = 0 Nighttime Max. 20% above Mean | R = 100 Daytime Min. Mean | R = 100 Daytime Min. 20% above Mean | R = 100 Nighttime Max. Mean | R = 100 Nighttime Max. 20% above Mean |
|---|---|---|---|---|---|---|---|---|---|
| Spring | Houston | 44.8 | 43.1 | 58.3 | 57.1 | 36.0 | 34.4 | 52.9 | 51.1 |
| | Average over 48 states | 46.5 | 45.1 | 59.6 | 58.3 | 37.0 | 35.4 | 53.6 | 52.2 |
| | Juneau | 49.6 | 47.9 | 69.1 | 69.1 | 39.9 | 38.3 | 58.3 | 57.1 |
| | Hawaii | 43.6 | 41.9 | 65.6 | 63.1 | 37.5 | 36.0 | 59.6 | 58.3 |
| Summer | Houston | 46.9 | 45.3 | 57.1 | 55.2 | 40.4 | 38.8 | 51.6 | 50.1 |
| | Average over 48 states | 48.3 | 46.9 | 57.1 | 55.2 | 41.7 | 40.2 | 52.2 | 50.6 |
| | Juneau | 48.7 | 47.2 | 55.2 | 53.6 | 43.3 | 41.7 | 51.6 | 50.1 |
| | Hawaii | 46.2 | 44.5 | 63.1 | 61.2 | 40.4 | 38.8 | 56.1 | 54.3 |
| Winter | Chicago | 45.6 | 44.0 | 65.6 | 63.1 | 35.6 | 34.0 | 59.6 | 58.3 |
| | Average over 48 states | 46.5 | 45.1 | 63.1 | 61.2 | 36.8 | 35.2 | 58.3 | 57.1 |
| | Juneau | 48.3 | 46.9 | 75.2 | 75.2 | 37.2 | 35.6 | 65.6 | 63.1 |
| | Hawaii | 46.9 | 45.3 | 65.6 | 63.1 | 40.2 | 38.6 | 63.1 | 61.2 |

Table 4. Cross-Polarization Discrimination Due to Faraday Rotation at 6 GHz (dB).

**Overall System XPD**

The combination of the depolarization due to the first four factors outlined in Section 1.0 will be an indication of the type of degradation in XPD. For worst case estimates, Tables 7 through 11 show the calculated overall system XPD where the satellite and earth station antennas are assumed to have an axial ratio of 33 and 35 dB, respectively. It can be observed that for heavy rainfall rates, the Faraday effect has much less influence as compared to the light rainfall conditions.

For any particular site one can determine the percentage of time for which the XPD is below a desired level. If this is found to be unacceptable, then some means of compensation (preferably adaptive) must be implemented in the feed circuitry which will raise the XPD to a desired level. In the next section we will discuss hardware available for frequency reuse feeds.

| | mm/hr (% of the time) \ Elev. Angle β | 10° | 20° | 30° | 40° |
|---|---|---|---|---|---|
| | | dB | dB | dB | dB |
| Canting Angle θ = 20° | 150 (0.01) | 12.71 | 14.49 | 17.82 | 20.87 |
| | 125 (0.0175) | 13.67 | 15.36 | 18.68 | 21.73 |
| | 100 (0.0425) | 15.20 | 16.81 | 20.14 | 23.19 |
| | 75 (0.11) | 17.49 | 19.0 | 22.35 | 25.42 |
| | 50 (0.25) | 20.36 | 21.78 | 25.14 | 28.27 |
| | 25 (1.0) | 25.0 | 26.32 | 29.81 | 33.20 |
| Canting Angle θ = 30° | 150 (0.01 | 9.92 | 11.76 | 15.14 | 18.21 |
| | 125 (0.0175) | 10.92 | 12.65 | 16.01 | 19.06 |
| | 100 (0.0425) | 12.49 | 14.13 | 17.48 | 20.51 |
| | 75 (0.11) | 14.82 | 16.34 | 19.67 | 22.68 |
| | 50 (0.25) | 17.69 | 19.10 | 22.42 | 25.42 |
| | 25 (1.0) | 22.28 | 23.56 | 26.86 | 29.88 |
| Canting Angle θ = 45° | 150 (0.01) | 8.52 | 10.42 | 13.85 | 16.93 |
| | 125 (0.0175) | 9.55 | 11.32 | 14.73 | 17.79 |
| | 100 (0.0425) | 11.16 | 12.82 | 16.20 | 19.25 |
| | 75 (0.11) | 13.52 | 15.06 | 18.41 | 21.43 |
| | 50 (0.25) | 16.42 | 17.84 | 21.16 | 24.17 |
| | 25 (1.0) | 21.02 | 22.31 | 25.61 | 28.63 |

Table 5. Cross-Polarization Discrimination Due to Rain at 4.0 GHz.

| | mm/hr (% of the time) \ Elev. Angle β | 10° | 20° | 30° | 40° |
|---|---|---|---|---|---|
| | | dB | dB | dB | dB |
| Canting Angle θ = 20° | 150 (0.01) | 8.42 | 10.21 | 13.54 | 16.59 |
| | 125 (0.0175) | 9.58 | 10.54 | 13.87 | 17.65 |
| | 100 (0.0425) | 11.13 | 12.74 | 16.08 | 19.11 |
| | 75 (0.11) | 13.31 | 14.82 | 18.15 | 21.18 |
| | 50 (0.25) | 16.80 | 18.21 | 21.55 | 24.61 |
| | 25 (1.0) | 21.41 | 22.7 | 26.09 | 29.26 |
| Canting Angle θ = 30° | 150 (0.01) | 5.29 | 7.26 | 10.78 | 13.90 |
| | 125 (0.0175) | 6.58 | 7.62 | 11.13 | 14.97 |
| | 100 (0.0425) | 8.26 | 9.95 | 13.38 | 16.44 |
| | 75 (0.11) | 10.54 | 12.10 | 15.48 | 18.51 |
| | 50 (0.25) | 14.12 | 15.54 | 18.88 | 21.89 |
| | 25 (1.0) | 18.74 | 20.02 | 23.34 | 26.36 |
| Canting Angle θ = 45° | 150 (0.01) | 3.58 | 5.73 | 9.41 | 12.60 |
| | 125 (0.0175) | 5.0 | 6.11 | 9.76 | 13.68 |
| | 100 (0.0425) | 6.78 | 8.56 | 12.06 | 15.16 |
| | 75 (0.11) | 9.16 | 10.76 | 14.19 | 17.24 |
| | 50 (0.25) | 12.81 | 14.26 | 17.61 | 20.64 |
| | 25 (1.0) | 17.47 | 18.76 | 22.07 | 25.10 |

Table 6. Cross-Polarization Discrimination Due to Rain at 6.0 GHz.

## Frequency Reuse Components and Feeds

### Four-Port Diplexer

The component which will separate the 4 and 6 GHz bands and which allows two orthogonal outputs in these two bands is described here in some detail. Figure 1 is a sketch showing the 4 GHz ports in the coaxial region and the 6 GHz ports in the smaller waveguide section. This component was developed by Bob Gruner of COMSAT Laboratories and has been shown to have excellent characteristics for frequency reuse applications.

The common waveguide is of 2-1/8″ diameter. The corrugated section in the common waveguide acts as a frequency diplexer. The depth of the corrugations are such that in the 4 GHz band the corrugated section supports a surface wave which is matched to the coaxial region. In the 6 GHz band the energy decays rapidly away from the centre and this is matched in the smaller inner circular waveguide. The latter is below cut-off for the 4 GHz signals. Photograph 0376-1 shows this diplexer with filters (to reject 6 GHz) attached to the 4 GHz ports. Not shown in this photograph is the 6 GHz orthomode transducer. The overall length of this diplexer is around 25 inches.

| | Elev. Angle $\beta$ / mm/hr (% of the time) | 10° | 20° | 30° | 40° |
|---|---|---|---|---|---|
| | | dB | dB | dB | dB |
| Canting Angle $\theta = 20°$ | 150 (0.01) | 12.0 | 13.6 | 16.5 | 19.1 |
| | 125 (0.0175) | 12.8 | 14.4 | 17.3 | 19.8 |
| | 100 (0.0425) | 14.2 | 15.7 | 18.5 | 20.9 |
| | 75 (0.11) | 16.2 | 17.5 | 20.3 | 22.6 |
| | 50 (0.25) | 18.7 | 19.8 | 22.4 | 24.5 |
| | 25 (1.0) | 22.3 | 23.2 | 25.4 | 27.2 |
| Canting Angle $\theta = 30°$ | 150 (0.01) | 9.3 | 11.1 | 14.2 | 16.9 |
| | 125 (0.0175) | 10.3 | 11.9 | 15.0 | 17.6 |
| | 100 (0.0425) | 11.8 | 13.3 | 16.2 | 18.8 |
| | 75 (0.11) | 13.9 | 15.2 | 18.1 | 20.6 |
| | 50 (0.25) | 16.4 | 17.6 | 20.4 | 22.7 |
| | 25 (1.0) | 20.3 | 21.3 | 23.7 | 25.7 |
| Canting Angle $\theta = 45°$ | 150 (0.01) | 8.0 | 9.8 | 13.0 | 15.8 |
| | 125 (0.0175) | 9.0 | 10.7 | 13.8 | 16.5 |
| | 100 (0.0425) | 10.5 | 12.1 | 15.1 | 17.8 |
| | 75 (0.11) | 12.7 | 14.1 | 17.0 | 19.6 |
| | 50 (0.25) | 15.3 | 16.6 | 19.4 | 21.7 |
| | 25 (1.0) | 19.2 | 20.3 | 22.8 | 24.9 |

Table 7. System Cross-Polarization Discrimination at 4 GHz
Faraday Rotation = 0 Degrees.

| | Elev. Angle $\beta$ / mm/hr (% of the time) | 10° | 20° | 30° | 40° |
|---|---|---|---|---|---|
| | | dB | dB | dB | dB |
| Canting Angle $\theta = 20°$ | 150 (0.01) | 11.5 | 13.1 | 16.0 | 18.4 |
| | 125 (0.0175) | 12.4 | 13.9 | 16.7 | 19.0 |
| | 100 (0.0425) | 13.7 | 15.1 | 17.8 | 20.0 |
| | 75 (0.11) | 15.7 | 16.9 | 19.4 | 21.4 |
| | 50 (0.25) | 18.0 | 19.0 | 21.3 | 23.0 |
| | 25 (1.0) | 21.2 | 21.9 | 23.6 | 24.9 |
| Canting Angle $\theta = 30°$ | 150 (0.01) | 9.1 | 10.8 | 13.9 | 16.5 |
| | 125 (0.0175) | 10.0 | 11.6 | 14.6 | 17.1 |
| | 100 (0.0425) | 11.5 | 13.0 | 15.9 | 18.3 |
| | 75 (0.11) | 13.6 | 14.9 | 17.6 | 19.9 |
| | 50 (0.25) | 16.0 | 17.2 | 19.7 | 21.6 |
| | 25 (1.0) | 19.6 | 20.5 | 22.5 | 23.9 |
| Canting Angle $\theta = 45°$ | 150 (0.01) | 8.0 | 9.8 | 12.9 | 15.6 |
| | 125 (0.0175) | 8.9 | 10.6 | 13.7 | 16.3 |
| | 100 (0.0425) | 10.4 | 12.0 | 14.9 | 17.5 |
| | 75 (0.11) | 12.6 | 14.0 | 16.8 | 19.1 |
| | 50 (0.25) | 15.1 | 16.3 | 18.9 | 21.0 |
| | 25 (1.0) | 18.8 | 19.7 | 21.9 | 23.5 |

Table 8. System Cross-Polarization Discrimination at 4 GHz
Faraday Rotation = 2.0 Degrees

| | Elev. Angle $\beta$ / mm/hr (% of the time) | 10° | 20° | 30° | 40° |
|---|---|---|---|---|---|
| | | dB | dB | dB | dB |
| Canting Angle $\theta = 20°$ | 150 (0.01) | 11.0 | 12.5 | 15.1 | 17.2 |
| | 125 (0.0175) | 11.8 | 13.2 | 15.7 | 17.7 |
| | 100 (0.0425) | 13.1 | 14.4 | 16.7 | 18.4 |
| | 75 (0.11) | 14.9 | 15.9 | 18.0 | 19.5 |
| | 50 (0.25) | 16.8 | 17.7 | 19.4 | 20.5 |
| | 25 (1.0) | 19.3 | 19.8 | 20.9 | 21.5 |
| Canting Angle $\theta = 30°$ | 150 (0.01) | 8.8 | 10.5 | 13.3 | 15.7 |
| | 125 (0.0175) | 9.7 | 11.2 | 14.0 | 16.3 |
| | 100 (0.0425) | 11.1 | 12.5 | 15.1 | 17.2 |
| | 75 (0.11) | 13.1 | 14.3 | 16.7 | 18.4 |
| | 50 (0.25) | 15.3 | 16.3 | 18.3 | 19.7 |
| | 25 (1.0) | 18.2 | 18.9 | 20.2 | 21.1 |
| Canting Angle $\theta = 45°$ | 150 (0.01) | 7.9 | 9.6 | 12.6 | 15.0 |
| | 125 (0.0175) | 8.8 | 10.4 | 13.3 | 15.7 |
| | 100 (0.0425) | 10.3 | 11.7 | 14.5 | 16.6 |
| | 75 (0.11) | 12.3 | 13.6 | 16.1 | 18.0 |
| | 50 (0.25) | 14.6 | 15.7 | 17.8 | 19.3 |
| | 25 (1.0) | 17.7 | 18.5 | 19.9 | 20.9 |

Table 9. System Cross-Polarization Discrimination at 4 GHz
Faraday Rotation = 4.0 Degrees

| | Elev. Angle β / mm/hr (% of the time) | 10° | 20° | 30° | 40° |
|---|---|---|---|---|---|
| | | dB | dB | dB | dB |
| Canting Angle θ = 20° | 150 (0.01) | 8.0 | 9.6 | 12.7 | 15.5 |
| | 125 (0.0175) | 9.1 | 10.0 | 13.0 | 16.4 |
| | 100 (0.0425) | 10.5 | 12.0 | 15.0 | 17.6 |
| | 75 (0.11) | 12.5 | 13.9 | 16.8 | 19.3 |
| | 50 (0.25) | 15.6 | 16.9 | 19.6 | 22.0 |
| | 25 (1.0) | 19.5 | 20.5 | 23.0 | 25.1 |
| Canting Angle θ = 30° | 150 (0.01) | 4.9 | 6.8 | 10.2 | 13.1 |
| | 125 (0.0175) | 6.2 | 7.2 | 10.5 | 14.0 |
| | 100 (0.0425) | 7.8 | 9.4 | 12.6 | 15.3 |
| | 75 (0.11) | 9.9 | 11.4 | 14.5 | 17.1 |
| | 50 (0.25) | 13.2 | 14.5 | 17.5 | 19.9 |
| | 25 (1.0) | 17.3 | 18.4 | 21.1 | 23.3 |
| Canting Angle θ = 45° | 150 (0.01) | 3.2 | 5.3 | 8.8 | 11.8 |
| | 125 (0.0175) | 4.6 | 5.7 | 9.2 | 12.8 |
| | 100 (0.0425) | 6.3 | 8.0 | 11.3 | 14.2 |
| | 75 (0.11) | 8.6 | 10.1 | 13.3 | 16.0 |
| | 50 (0.25) | 12.0 | 13.4 | 16.4 | 18.9 |
| | 25 (1.0) | 16.2 | 17.3 | 20.1 | 22.4 |

Table 10. System Cross-Polarization Discrimination 6 GHz
Faraday Rotation = 0 Degrees

| | Elev. Angle β / mm/hr (% of the time) | 10° | 20° | 30° | 40° |
|---|---|---|---|---|---|
| | | dB | dB | dB | dB |
| Canting Angle θ = 20° | 150 (0.01) | 7.5 | 9.2 | 12.3 | 14.9 |
| | 125 (0.0175) | 8.6 | 9.5 | 12.6 | 15.8 |
| | 100 (0.0425) | 10.1 | 11.6 | 14.5 | 17.0 |
| | 75 (0.11) | 12.1 | 13.4 | 16.2 | 18.6 |
| | 50 (0.25) | 15.1 | 16.3 | 18.9 | 20.9 |
| | 25 (1.0) | 18.8 | 19.7 | 21.8 | 23.4 |
| Canting Angle θ = 30° | 150 (0.01) | 4.7 | 6.6 | 9.9 | 12.8 |
| | 125 (0.0175) | 5.9 | 6.9 | 10.2 | 13.7 |
| | 100 (0.0425) | 7.5 | 9.1 | 12.3 | 15.0 |
| | 75 (0.11) | 9.7 | 11.1 | 14.2 | 16.7 |
| | 50 (0.25) | 13.0 | 14.2 | 17.0 | 19.3 |
| | 25 (1.0) | 16.9 | 17.9 | 20.3 | 22.2 |
| Canting Angle θ = 45° | 150 (0.01) | 3.2 | 5.3 | 8.8 | 11.8 |
| | 125 (0.0175) | 4.6 | 5.7 | 9.1 | 12.7 |
| | 100 (0.0425) | 6.3 | 8.0 | 11.3 | 14.0 |
| | 75 (0.11) | 8.6 | 10.1 | 13.2 | 15.8 |
| | 50 (0.25) | 12.0 | 13.3 | 16.1 | 18.5 |
| | 25 (1.0) | 16.0 | 17.1 | 19.6 | 21.6 |

Table 11. System Cross-Polarization Discrimination at 6 GHz
Faraday Rotation = 2.0 Degrees.

**Polarization Tracking Feed**

In order that Faraday effects can be compensated completely, it is necessary to rotate the 4 and 6 GHz ports in the opposite directions. Figure 2 is a block diagram showing the feed in detail. The packages within the dashed areas 1 and 2 rotate independently of each other, thus allowing the freedom between the 4 and 6 GHz bands. Low-noise amplifiers in the receive band can be part of the rotating package 1. For rotation of the 6 GHz signal vector, a motor-driven half-wave polarizer will suffice. For maximizing the XPD the signal in the undesired port has to be minimized. Appropriate rotation can be accomplished by proper feedback circuitry.

The above feed will only compensate for polarization mismatch and in the 4 and 6 GHz bands, this means the worst case system XPD achievable will be about that shown in Tables 7 and 10. For some site requirements this XPD may not be above a desirable level for heavy rainfall rates. In this case a feed with ellipse tracking capability is also required.

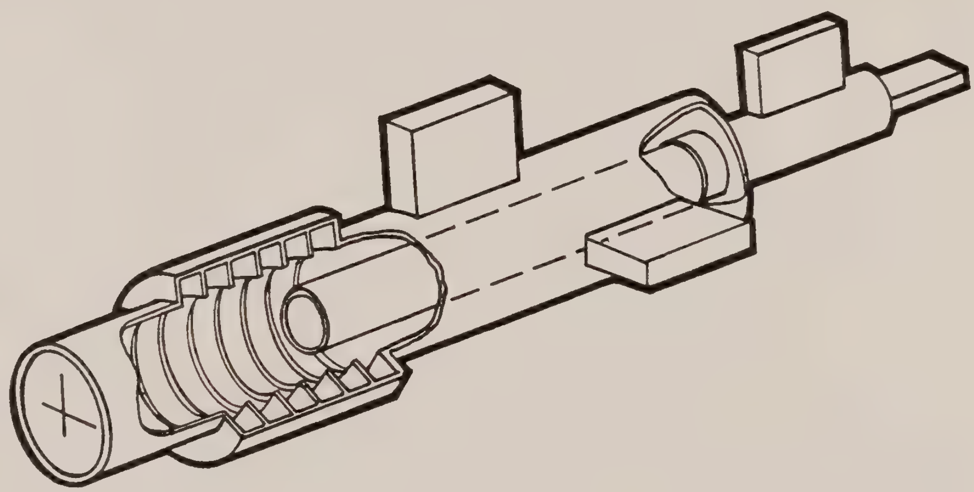


Figure 1

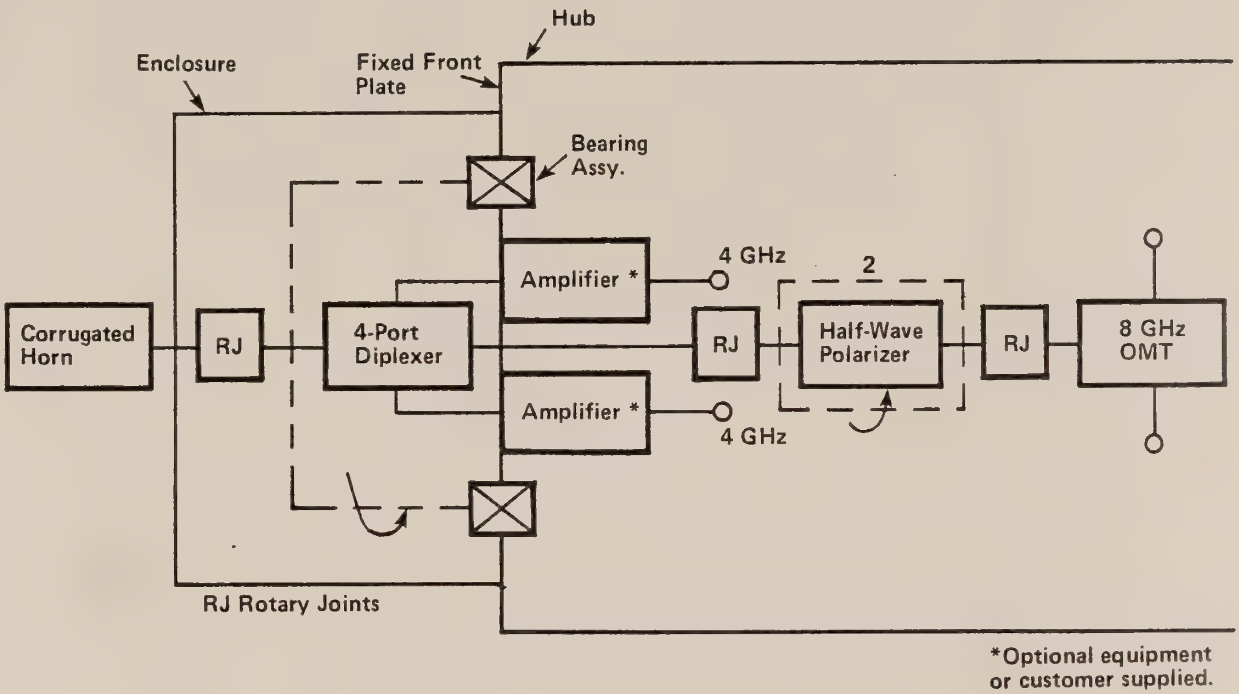
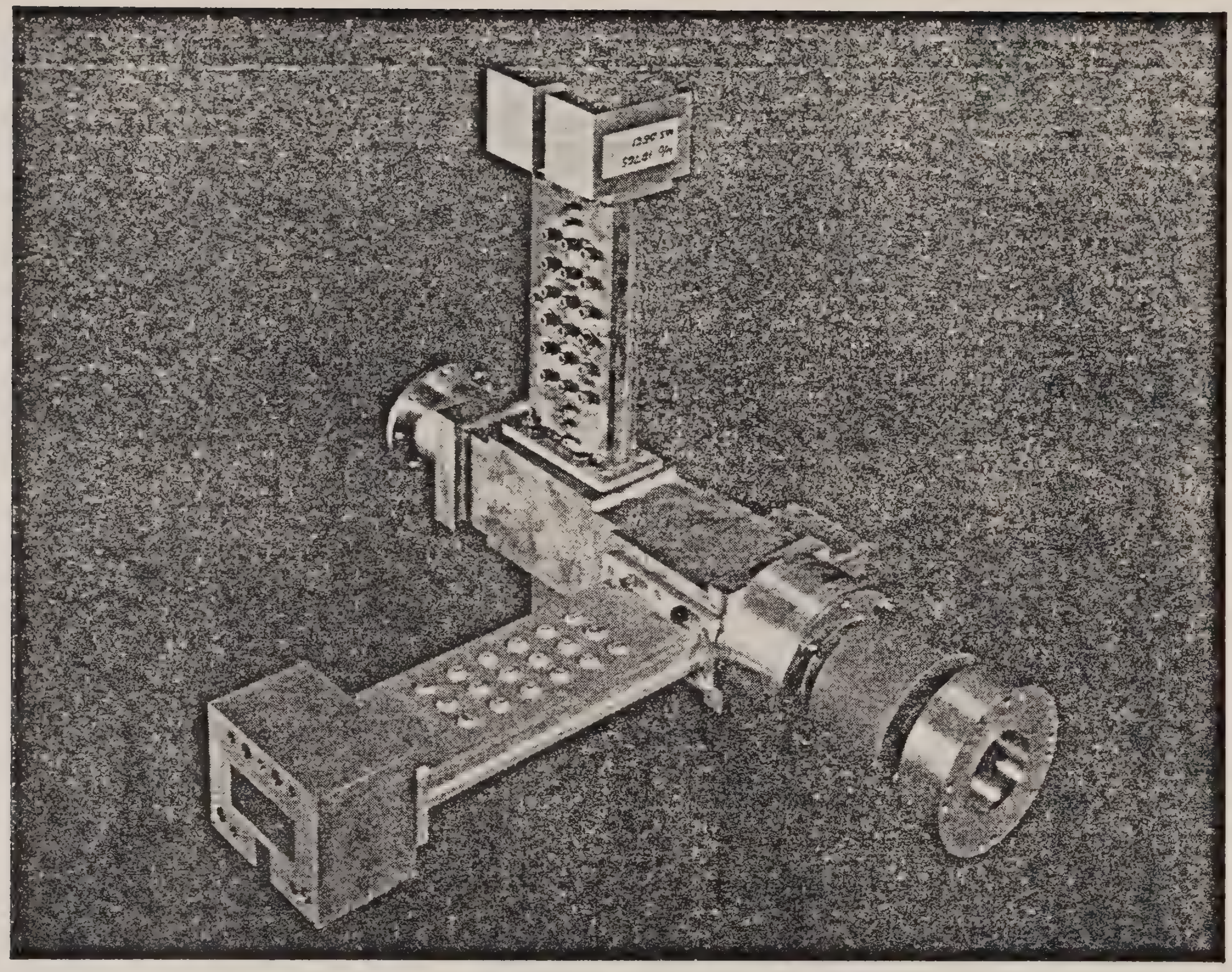



Figure 2. Model 8231 Frequency Reuse Feed Simplified Block Diagram.

**Polarization and Ellipse Tracking Feed**

It has been proposed * that a simple mechanism which compensates for both polarization angle and polarization ellipse is a cascade of quarter-wave and half-wave polarizers. The purpose of the quarter-wave polarizer is to linearize the finite axial ratio ellipse and the half-wave polarizer essentially rotates the wave to polarization match to the desired output ports. As has been noted previously the differential phase due to rain introduces a finite axial ratio; then with the aid of a quarter-wave polarizer, the polarization can be linearized. The feed circuitry that comprises Scientific-Atlanta Model 8232 Feed is shown as a block diagram in Figure 3. Note, now the only rotating components are the polarizers in the 4 and 6 GHz channels. The feed complexity is increased manifold as compared to the previously described feed. In order to compensate for axial ratio and polarization at 4 GHz a somewhat more elaborate four-port diplexer is required. This diplexer is actually a combination of two four-port diplexers where in Figure 3 one is referred to as the main and the other as the auxiliary four-port diplexer. The elaborate feed provides the capability to independently adjust the 4 and 6 GHz components. The diplexer unit is shown in Photographs 0376-2 and 0376-3. Photograph 0376-6 shows the complete feed network where the 6 GHz channel of the auxiliary diplexer is shorted. Note, only the polarizers are motor-driven for adjustment purposes.

* D.F. DiFonzo, et al, "Adaptive Polarization Control for Satellite Frequency Reuse Systems," COMSAT Tech. Review, Volume 6, No. 2, Fall, 1976.



Basic Four-Port Orthomode Junction, Photo 0376-1

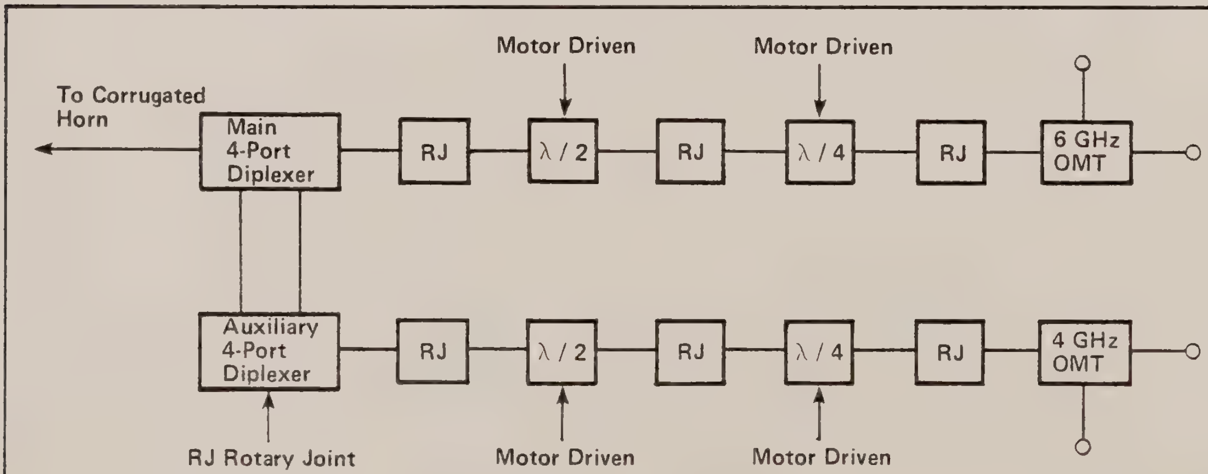


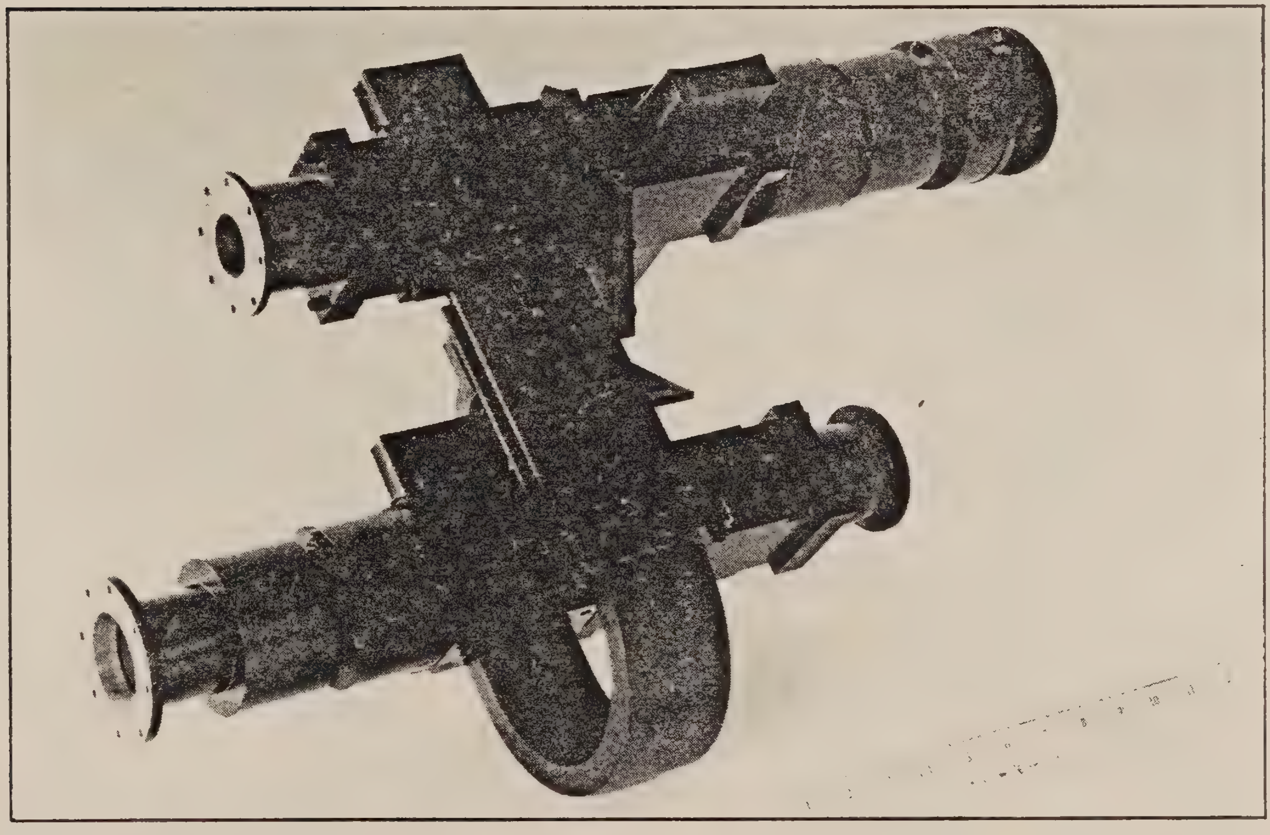

Figure 3. Model 8232 Frequency Reuse Feed Simplified Block Diagram.

For an incoming signal at 4 GHz, the signal in the undesired port is minimized by rotating each polarizer one at a time. Obviously, some sort of algorithm is required to command the components for rotation. The 6 GHz polarizers can be appropriately positioned so that the signal received at the undesired channel of the satellite is minimized. This sets a more difficult task for the transmit band unless a closed-loop type of feedback is available.

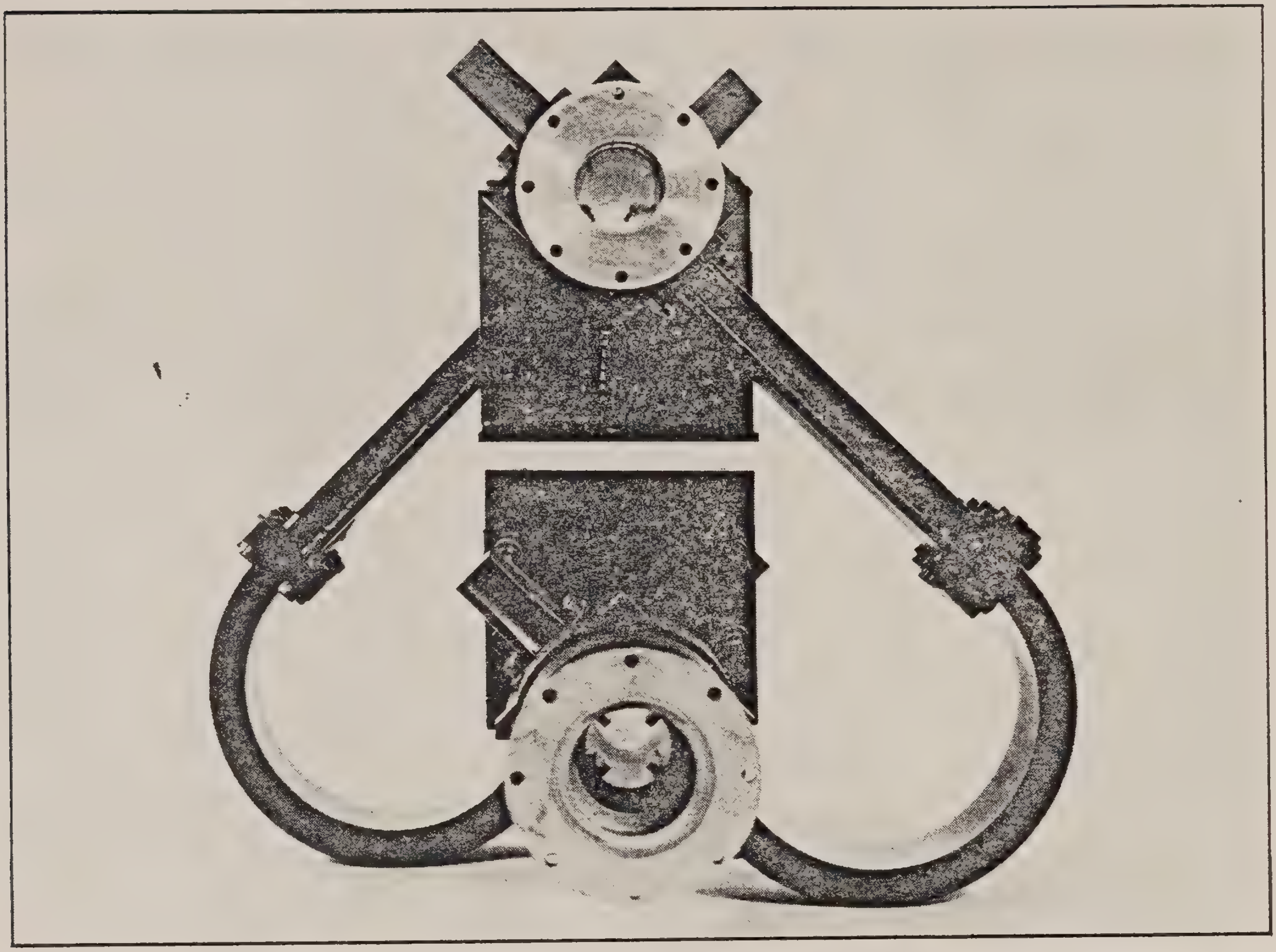
The XPD that can be realized with the feed is better than that obtained from the previously described feed provided the rainfall is significant. However, for the latter case the differential attenuation due to rain would act as a limiting factor. The XPD due to this effect at 4 and 6 GHz is shown in Table 12. It can be seen that despite this limitation, the XPD is probably sufficient for 99.96% of the time.

| Rain Rate (mm/hr) | XPD (dB) | |
|---|---|---|
| | 4 GHz | 6 GHz |
| 150 | 34.5 | 19.5 |
| 125 | 37.0 | 21.5 |
| 100 | 40.0 | 24.5 |
| 75 | 44.0 | 28.5 |
| 50 | 48.5 | 34.0 |
| 25 | > 50.0 | 43.0 |

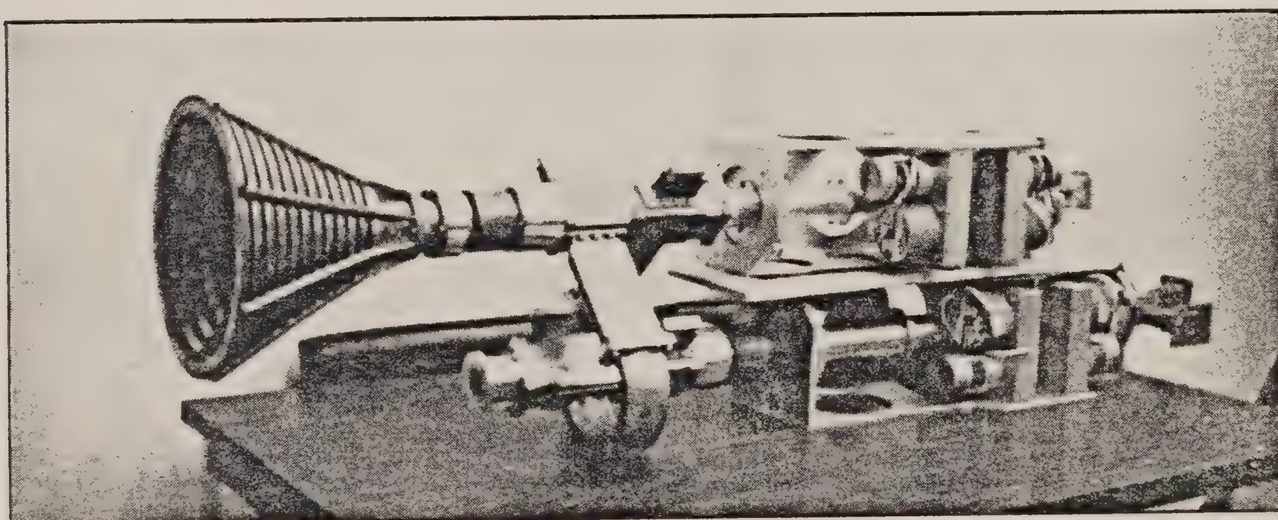
Table 12. Cross-Polarization Discrimination Due to Differential Attenuation Only.



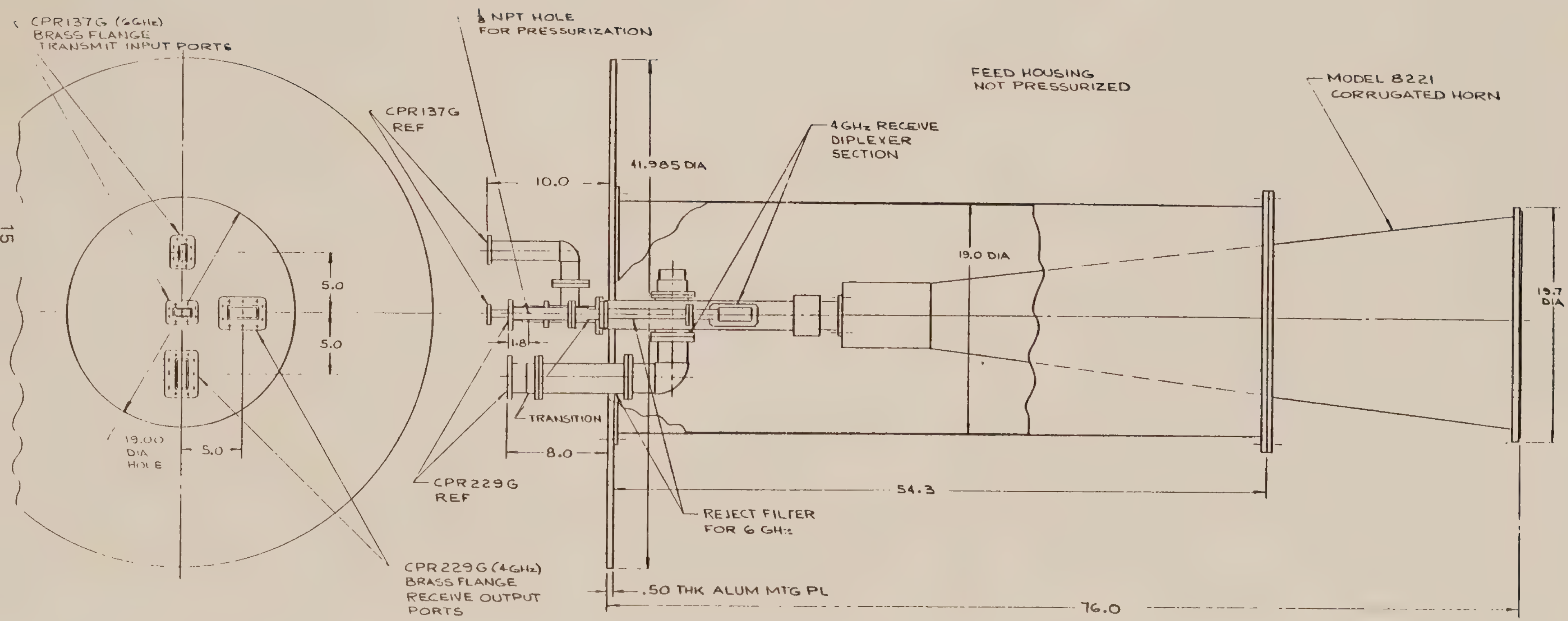
Dual Polarized Diplexer, Side View, Photo 0376-2



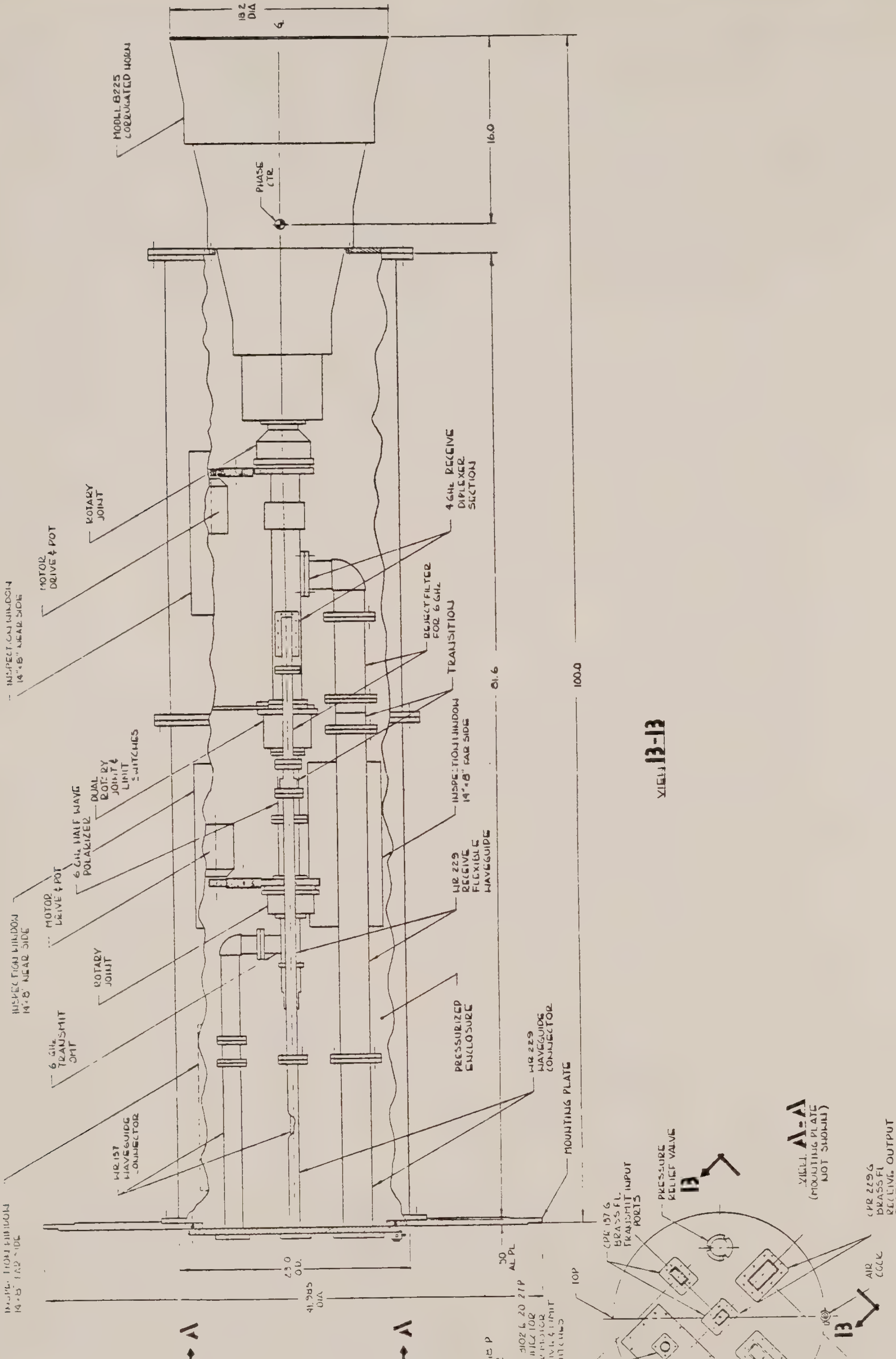
Dual Polarized Diplexer, Front View, Photo 0376-3



Frequency Reuse Feed Polarization Ellipse Tracker, Photo 0376-6




NOTE:
1. FEED USED WITH 10M SHAPED REFL


18.2 DIA
MODEL 8225 CORRUGATED HORN
PHASE CTR
16.0
ROTARY JOINT
MOTOR DRIVE & POT
4 GHz RECEIVE DIPLEXER SECTION
REJECT FILTER FOR 6 GHz
TRANSITION
81.6
100.0
DUAL ROTARY JOINT & LIMIT SWITCHES
6 GHz HALF WAVE POLARIZER
INSPECTION WINDOW 14"×8" FAR SIDE
WR 229 RECEIVE FLEXIBLE WAVEGUIDE
MOTOR DRIVE & POT
ROTARY JOINT
6 GHz TRANSMIT OMT
PRESSURIZED ENCLOSURE
WR 229 WAVEGUIDE CONNECTOR
MOUNTING PLATE
WR 137 WAVEGUIDE CONNECTOR
23.0 OD
41.995 DIA
5.0 AL PL
VIEW B-B
VIEW A-A (MOUNTING PLATE NOT SHOWN)
PRESSURE RELIEF VALVE
CPR 137 G BRASS FL TRANSMIT INPUT PORTS
CPR 229 G BRASS FL RECEIVE OUTPUT PORTS
AIR COCK
10P
B
A

# STRUCTURAL DESIGN

Fred Fonda
Manager, Structures Engineering
Antenna & Microwave Product Line

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Introduction**

The subject of structural design of earth terminal for satellite communication must start with an understanding of earth satellite geometry. With this understanding it is then possible to define the positioning requirements of the earth terminal antenna.

The fraction of hemispherical area of sky covered by the pencil beam of an earth terminal antenna is quite small.

The fraction is $\dfrac{1}{\left(\dfrac{1}{1-\cos\theta/2}\right)}$

where $\theta$ is the half power beam width of the antenna

A 5 meter antenna having a nominal beamwidth of 1° at 4 GHz covers one part in 26,000 of the hemisphere. The 10 meter coverage is 1/4 or one part in 104,000. Thus locating a satellite requires accuracy in positioning relative to known geographical coordinates. Reliable communication performance requires that the antenna mount structure have rigidity to maintain this position under operating environments.

**Satellite - Earth Geometry**

Figure 1 is a space view from above the earth showing some of the domestic satellites at their respective longitudinal positions. These satellites are at a radius from the center of the earth of 6.611 earth radii. At this radius the period of one orbital rotation for a satellite is equal to the period of earth rotation. The orbital plane of these satellites passes through the equatorial plane of the earth. Therefore because of these two contraints (i.e.) a circular orbit about the earth with a radius of 6.611 earth radii and the plane of the orbit lying in the equatorial plane of the earth the satellites appear stationary with respect to any point on the earth.

**Antenna Positioning Systems**

There are many different multi-axis configurations which will allow pointing the antenna at a given point in the hemisphere. Some of the more common ones are elevation-over-azimuth, X-Y, and polar. Scientific-Atlanta has produced all three of these types for its earth terminals. Each has its own merits and brief discussion of each follows.

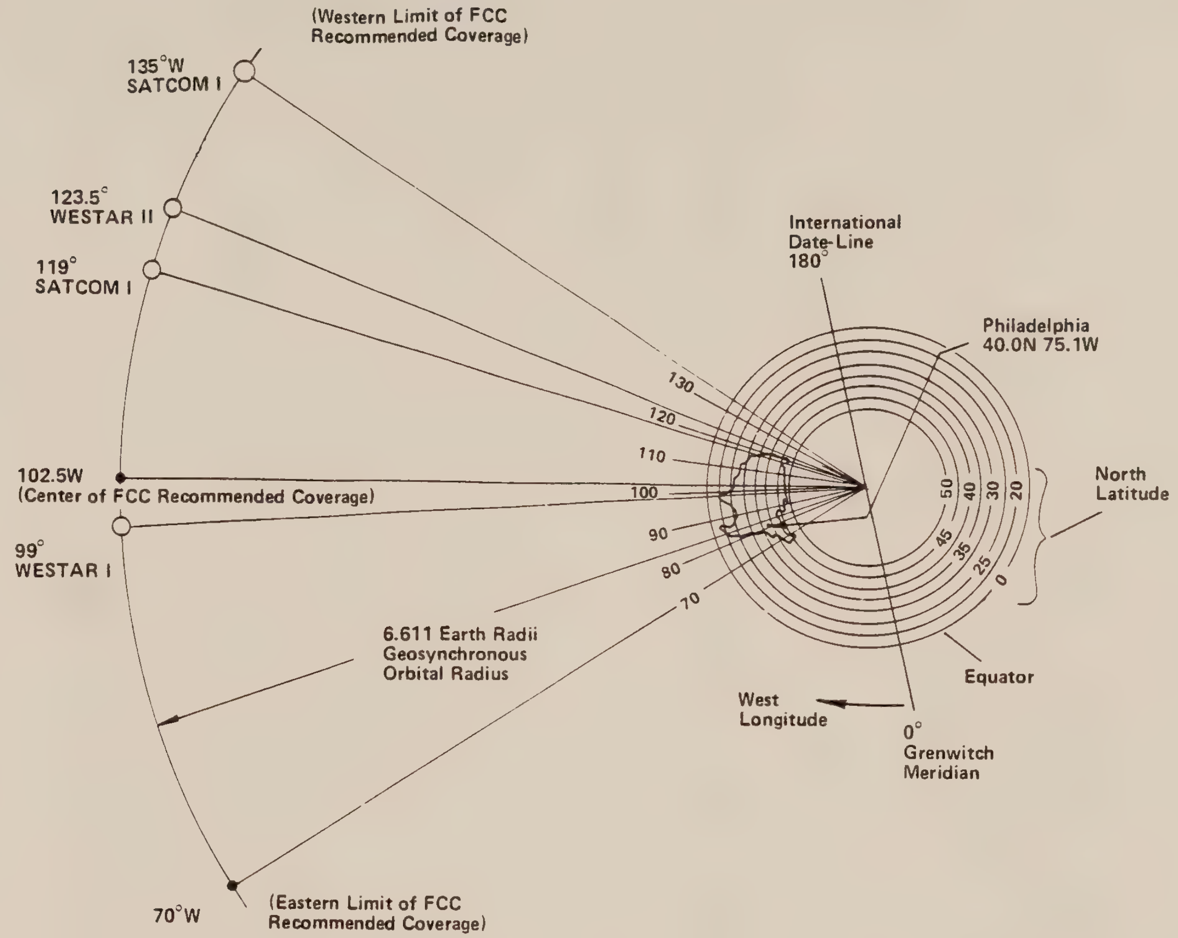



Figure 1. Space Earth-Satellite View (from above)

**Elevation-over-Azimuth Pointing System**

A universal method of describing the direction of a point on earth as well as points in space with respect to a point on earth is the azimuth-elevation coordinate system. The familiar method describing a place as being, for example, "east" of here is in reality using an azimuth measuring system referenced to north. The place then is 90 degrees true azimuth from here. Furthermore, if the place were on a high mountain and one had to aim an antrenna to point to the place on the mountain one would use a transit to measure the elvation angle from horizontal to the top of the mountain. The antenna would then be elevated to this angle using its elevation read-out counter if the mount is an elevation-over-azimuth configuration. A boresight telescope and/or coordinate transformation calculations are not required for pointing an antenna mounted to an elevation-over-azimuth positioner.

Figure 2 shows the elevation-over-azimuth mount geometry. Azimuth is the lowermost axis. It is perpendicular to the local ground horizontal plane. True azimuth is the angle in the horizontal plane measured clockwise from north. Elevation is measured in a vertical plane with zero degrees occurring with the line of site at the horizon.

The initial installation of an elevation over azimuth positioner is not critical. The azimuth axis must be nearly vertical so that an azimuth sweep couples in a minimum change in elevation angle. The Scientific-Atlanta 5 and 10 Meter mounts, if installed with their 3 feet within 1/8 inch of being level, will have an elevation pointing error of less than 0.1 degree for a 50 degree change of azimuth position. Minimum and maximum elevation angles for covering satellites between 70 and 135° W longitude are given in Figure 3 for the United States. Note that except for the northeastern New England States and the northwest tip of Washington, the minimum required elevation look angle is greater than 15 degrees. For this major portion of the United States, the Scientific-Atlanta 8024A short 10 meter mount may be used to an advantage where local building codes have strict height limitations. The short mount reduces foundation loadings about 25% and thus can mean cost savings in concrete and reinforcing bars.

The azimuth center heading of the positioner should be selected to insure coverage of satellites located anywhere from 70 to 135° West longitude. Figure 4 gives the total azimuth sweep necessary in the United States for this coverage. Note that the required sweep increases for lower latitudes. Figure 4 also shows the azimuth center heading of the positioner for equal clockwise and CCW pointing angles to cover the 70 to 135 degree orbital arc.

Figure 5 is a universal set of azimuth-elevation look angles versus a particular site latitude and the longitudinal difference between the satellite and the site. The horizontal and vertical rectangular coordinates are site latitude and difference longitude respectively. The curved lines running toward and labled at the top of the graph are the required azimuth look angles (add to 180° if satellite is west of site, subtract from 180° if satellite is east of site). The curved line running toward and labled at the left margin (down to 15 degrees) are required elevation look angles. (The elevation lines of 10° and below are labled at the top of the graph). To determine required az and el look angles determine the satellite-site longitudinal difference and move vertically on this line until it intersects the horizontal site latitude line. At this intersection interpolate between bounding azimuth and elevation curves for the required look angles. (Make the 180° azimuth correction as noted above). This graph and its derivation is contained in the appendix.

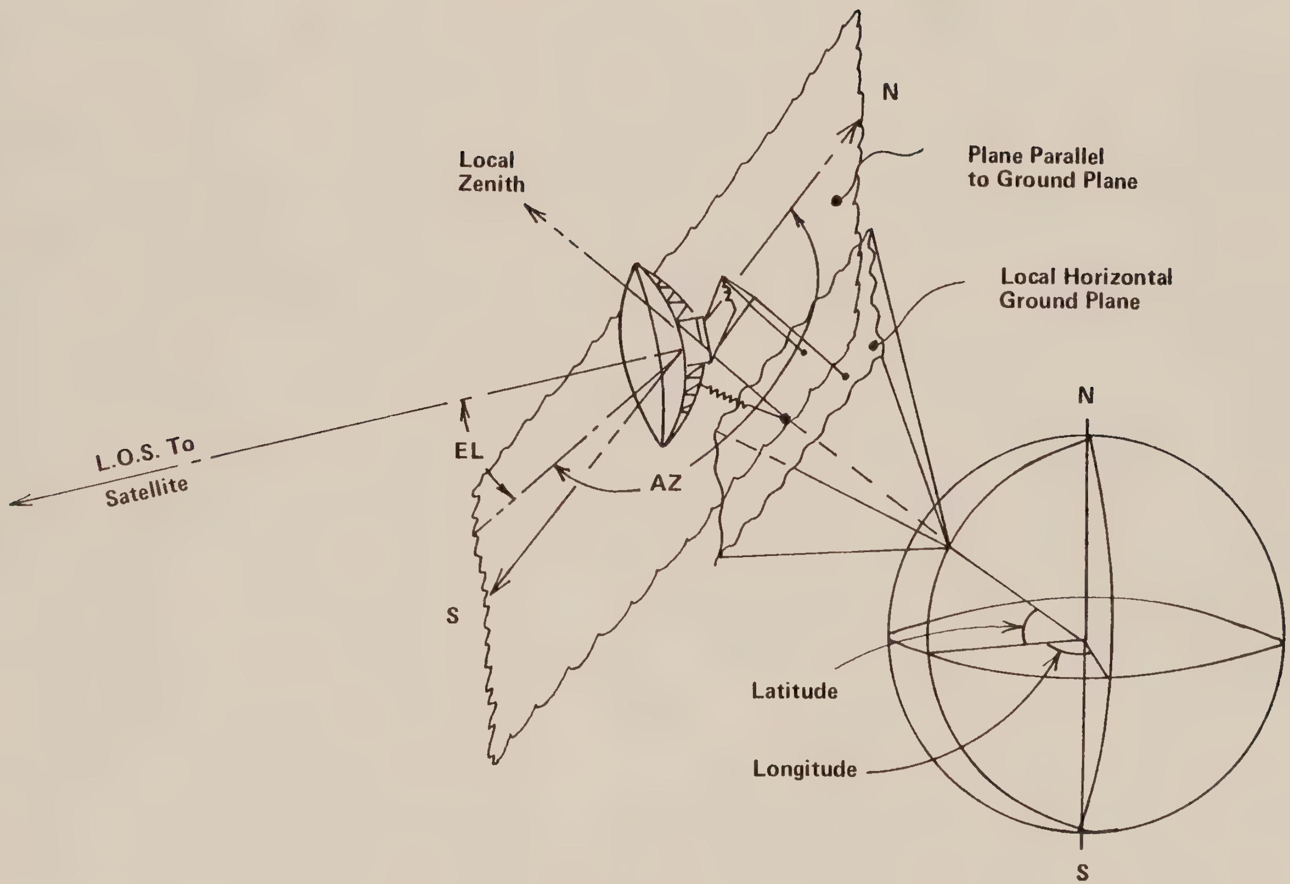
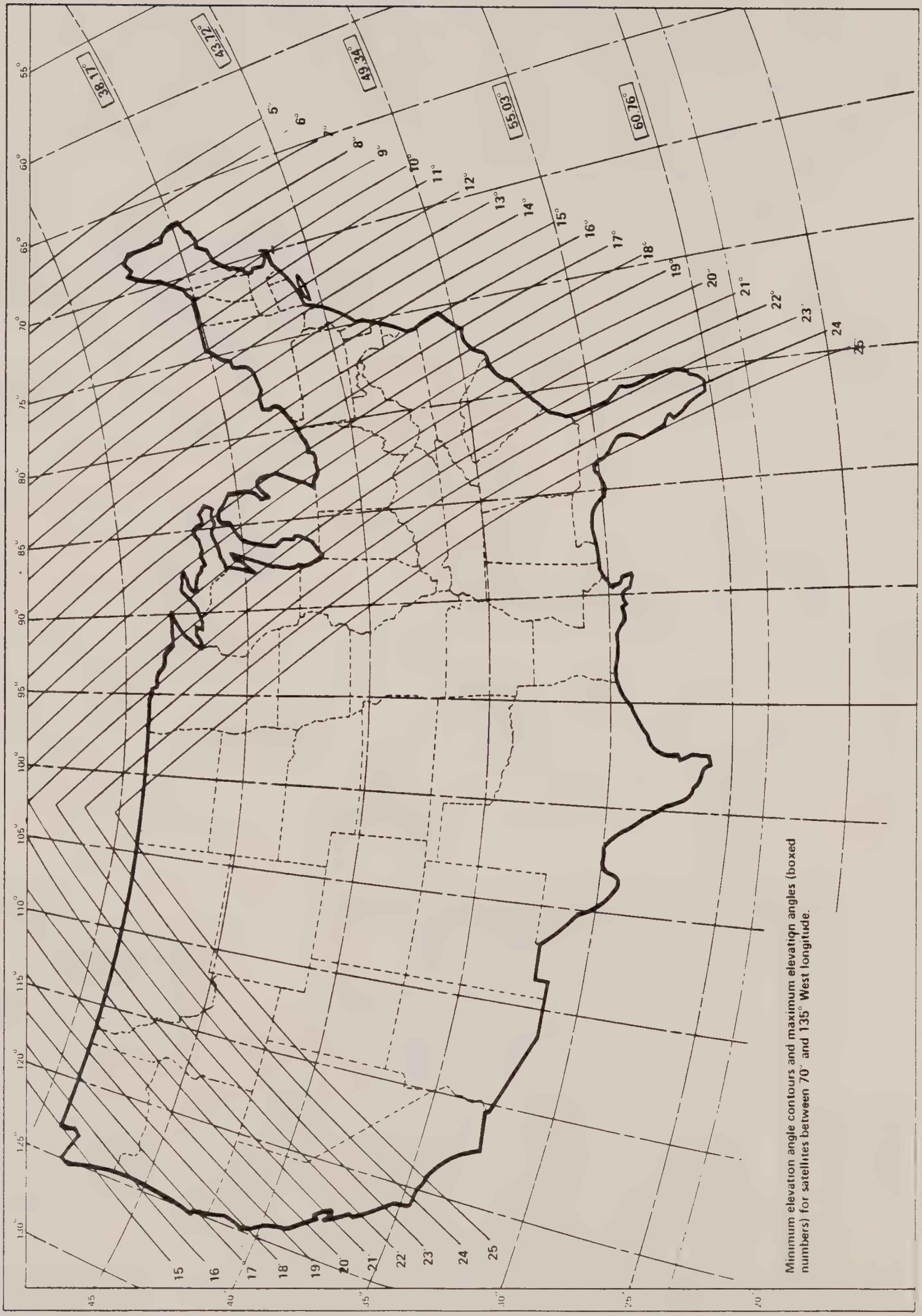



Figure 2. Elevation Over Azimuth Mount Geometry.




Minimum elevation angle contours and maximum elevation angles (boxed numbers) for satellites between 70° and 135° West longitude.

Figure 3.


130°
125°
120°
115°
110°
105°
100°
95°
90°
85°
80°
75°
70°
65°
60°
55°
45°
40°
35°
30°
25°
20°
155°
160°
165°
170°
175°
180°
185°
190°
195°
200°
205°
210°
215°
75°
80°
85°
90°
95°
100°
105°
110°
Vertical contours indicate foundation center line heading and antenna true heading at center of coverage sector.
Horizontal contours indicate required antenna azimuth travel for satellites located between 70° and 135° West longitude.

Figure 4.

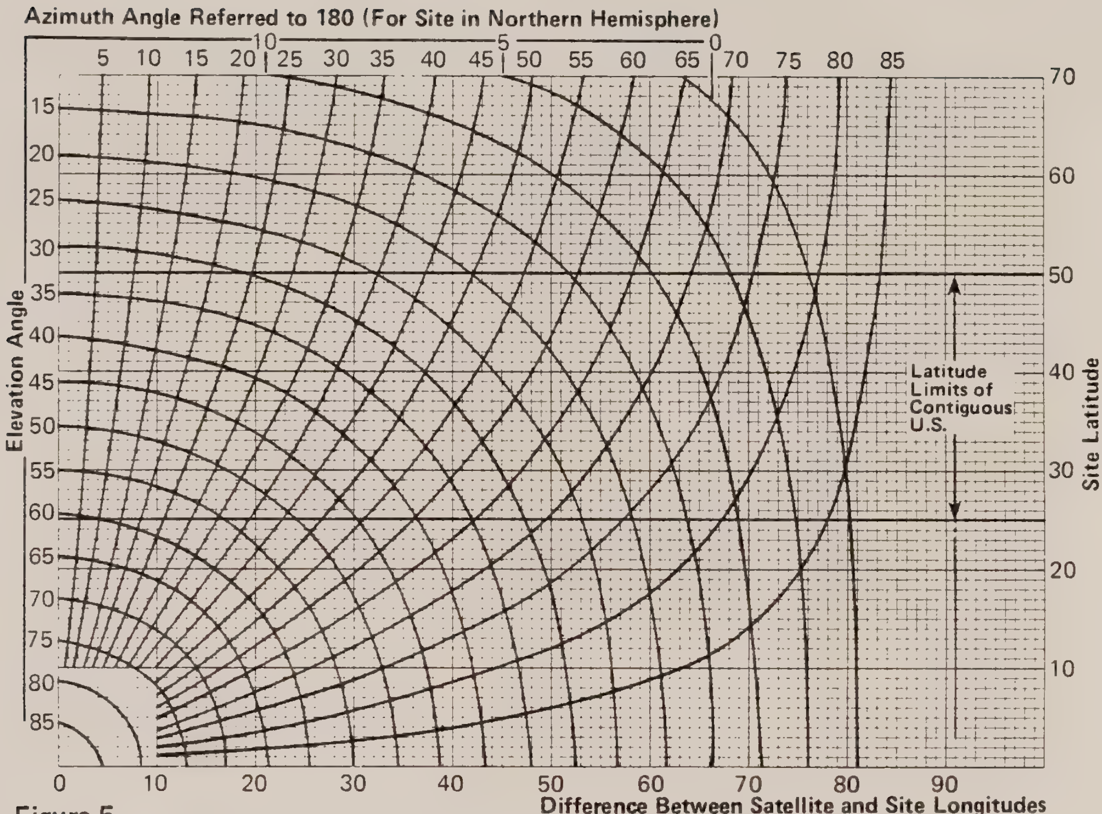

Azimuth Angle Referred to 180 (For Site in Northern Hemisphere)
10
5
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
Elevation Angle
15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
Site Latitude
70 60 50 40 30 20 10
Latitude Limits of Contiguous U.S.
0 10 20 30 40 50 60 70 80 90
Difference Between Satellite and Site Longitudes

Figure 5.

**X-Y Axes Pointing System**

Structurally, one of the least complicated and hence most cost effective positioning-support systems is the X-Y Axes configuration. This geometry is shown in Figure 6. The X-Y mount is sometimes called azimuth-over-elevation. This is really a miss-naming because azimuth is generally defined as the arc sweep of the horizon. Figure 6 shows the lowermost axis designated, X1. This axis is parallel to the ground and in this example passes through the rear two feet of the mount. Rotation about this axis (by changing the length of the front foot or the lengths of the two rear feet) gives an elevation like rotation of the antenna. The Y1 axis lies in a vertical plane which is perpendicular to the X1 axis. The position of the Y1 axis in the vertical plane can range from vertical to horizontal depending upon rotation of the X1 axis. Note that the mount heading is designated as A1. This angle measured from north is to the projection of the Y1 axis onto the horizontal plane. It is established during installation of the foundation. The proper value of A1 for Scientific-Atlanta's X-Y mount systems is the same as the foundation center line heading for elevation-over-azimuth mounts given in Figure 4.

Therefore, whether installing an Scientific-Atlanta elevation-over-azimuth or X-Y mount the proper foundation heading is the mid azimuth between the local azimuth to the 70° and the 135° satellites.

The allowable error in foundation heading for either the Scientific-Atlanta elevation-over-azimuth or X-Y mounts is a function of required azimuth coverage and available mount travel. Scientific-Atlanta's mounts provide at least 110° of azimuth travel. Referring agin to Figure 4, it is seen that only at the southernmost region of Texas is 110° azimuth coverage required to sweep all satellites between 70° and 135° west. For these southernmost location it is best to add whatever survey uncertainty exists to the theoretical azimuth heading so that the system tends to be biased in a westerly direction. Then whatever center line error exists any missed coverage will be the eastern end of the orbit (the 70° end) and for certain the 135° satellite can be reached.

With due consideration to the azimuth coverage requirement the other aspect of foundation heading is satellite acquisition. Satellite look angles are easily and hence most often given in terms of local azimuth and elevation angles. (The equations are given in the appendix). For a Scientific-Atlanta elevation-over-azimuth as well as its 8005 X-Y earth terminal the satellite is most easily acquired by setting the elevation angle and sweeping in azimuth to intercept the satellite. An effective way to measure absolute elevation of the antenna independently of any mechanical errors is to use an inclinometer. This is simply a protractor with a bubble level reference. There are many makes available which cost around $20.00 and are accurate to ±0.5°. The inclinometer should be set in the rear of the feed mounting plate and aligned approximately in the local vertical plane. The 10 dB beamwidth of the Scientific-Atlanta's 10 meter antennas is approximately 1.0 degree. Therefore, with a ±0.5° elevation setting uncertainty the satellite should come up when it is intercepted during an azimuth sweep.

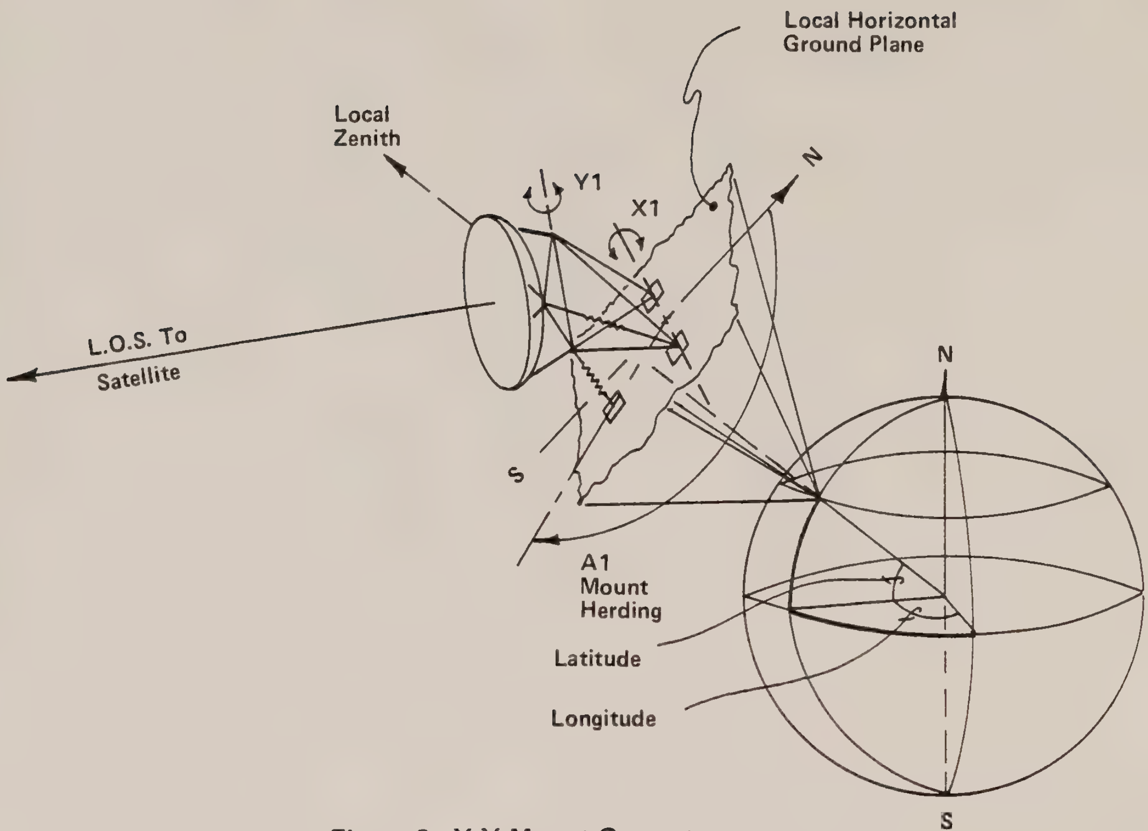



Figure 6. X-Y Mount Geometry.

There is some cross coupling of elevation angle when sweeping about the Y1 axis of an X-Y mount. This ratio of cross coupling is given in Figure 7. It is seen that only at high values of X1 angle (which can occur at southern latitudes) and large values of Y1 angle off of dead ahead do significant portions of Y1 motion couple into elevation position. For the Scientific-Atlanta's 8005 4.6 Meter X-Y Earth Terminal a worst case change in elevation occurring with a 5 degree foundation error is slightly over 1 degree. The 10 dB beamwidth of the 4.6 meter antenna is slightly greater than 2 degrees. So even if an elevation correction is not made during a sweep to acquire the satellite it would be detected with the 8005 earth terminal with as much as a 5 degree heading uncertainty.

Boresighting or calibrating the rotational position references of an elevation-over-azimuth mount is a simple matter. After a satellite with known longitude is acquired the elevation and azimuth axes degree dials or counters are slipped to the correct azimuth and elevation heading to the satellite. Thereafter, regardless of foundation center line error the mounts azimuth and elevation indicators can be used to point the antenna to alternate satellites.

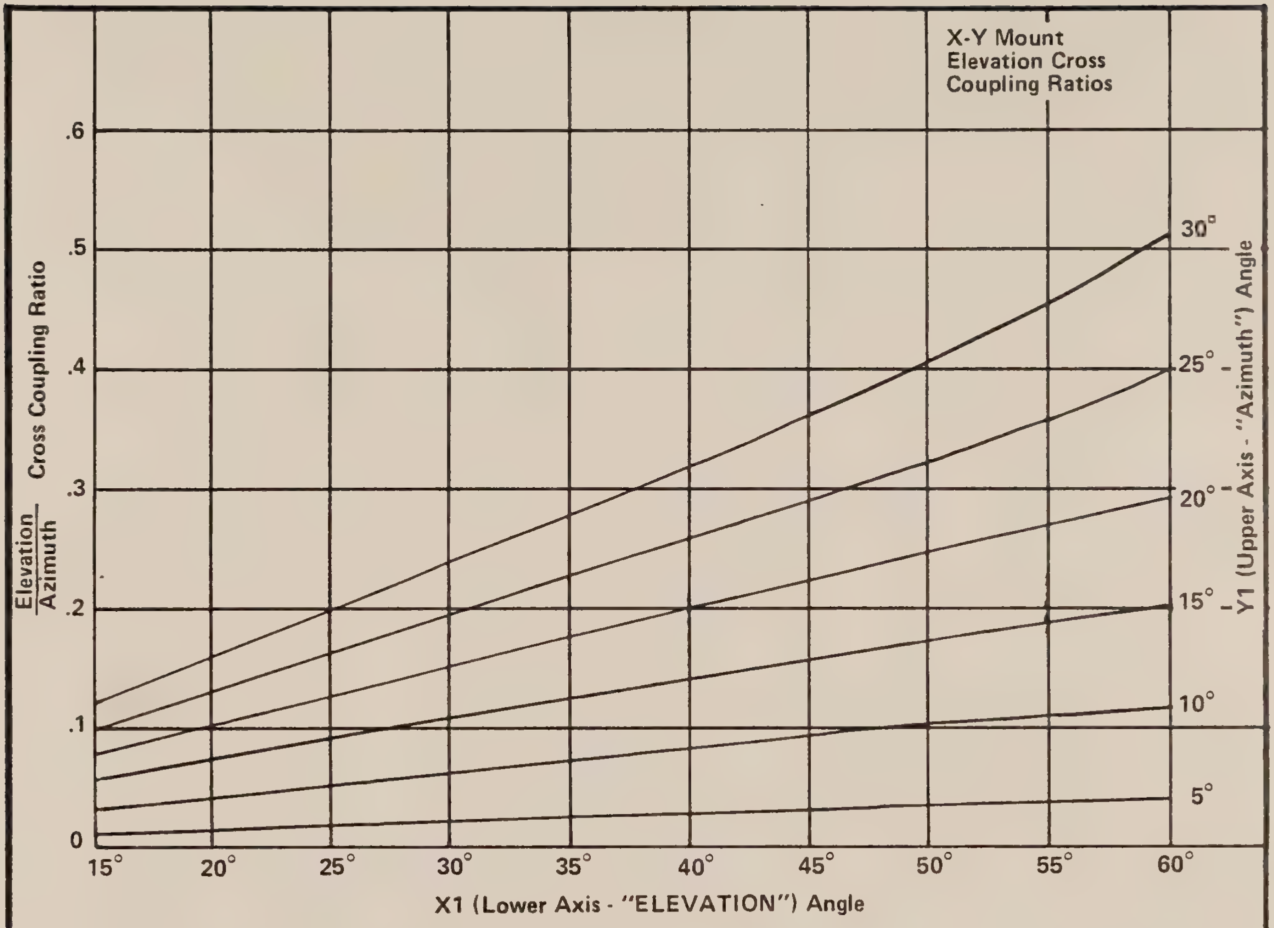

X-Y Mount
Elevation Cross
Coupling Ratios
Elevation / Azimuth Cross Coupling Ratio
.6
.5
.4
.3
.2
.1
0
15°
20°
25°
30°
35°
40°
45°
50°
55°
60°
X1 (Lower Axis - "ELEVATION") Angle
30°
25°
20°
15°
10°
5°
Y1 (Upper Axis - "Azimuth") Angle

Figure 7.

Boresighting an X-Y mount is almost as easy. The one difference is that to perform this calibration on an X-Y mount the mount heading must be determined. After this has been done, the X-Y look angles are easily calculated for the satellite at the site. For the Scientific-Atlanta's 8005 X-Y Earth Terminal, the measurement of the length of the 3 telescoping support legs is the most accurate and straight forward measurement of X-Y pointing angles. Look-up tables are provided which give required leg lengths for all combinations of X-Y pointing angles.

The true foundation center line azimuth angle may be determined several different ways. A survey may be made using a transit to sight on objects of known true bearing. A Polaris sighting may be made at night or a local noon sun shot all can be used to directly measure the foundation true azimuth.

An indirect method using an inclinometer to measure X angle of the antenna peaked up on a particular satellite is an alternative. For the Scientific-Atlanta 8005 X-Y Earth Terminal, the look-up tables may be used instead of an inclinometer for determining X angle. The tables are entered with 2 leg lengths and X angle is directly read. Using a simple formula (see appendix) and entering the value for X, satellite and site longitude and site latitude and satellite azimuth, the true foundation azimuth heading may be calculated.

Having the local true foundation centerline, the X and Y look angles for any satellite may be calculated entering the formulas (see appendix) with centerline heading, satellite and site longitude and site latitude.

## Polar Mount Pointing System

A polar mount has two axes of rotation named hour angle and declination. Figure 8 shows its geometry. The hour angle axis is inclined to local horizontal equal to the sites latitude. Thus this axis is parallel to the ground at the equator and perpendicular at either pole. This axis is aligned parallel with the earth's axis. Therefore, in addition to being inclined with local level to local latitude it is aligned in a north-south direction. When this alignment is achieved it is possible by rotating about this axis at one revolution per day to keep the line of sight steady with respect to a stationary point in space. Most astronomical telescopes have the polar axis configuration because of this characteristic. With zero declination angle (the antenna line of sight perpendicular to the hour angle axis) sweeping about the hour angle axis could scan the antenna beam in a plane parallel to the plane passing through the equator. To intercept a synchronous satellite on this plane the antenna must be depressed in declination because of the finite orbital radius of the satellite. The amount of declination required is a function of the relative longitudinal difference between the satellite and the site. This is so because the distance to the satellite changes with differences in satellite-site longitude. It would not change if the terminal were at the earth's center. A polar mount located in Philadelphia for instance has a .41 degree required change in declination covering satellites between 70° and 135°W longitude. It is possible to reduce this required declination change by over an order in magnitude by introducing a correction tilt to the hour angle axis during initial system installation. The possibility then exists that such a system carefully installed could peak up on any satellite between 70° and 135° by rotating about one axis only. The practical problems of pouring a foundation to the accuracy required for one axis operation are such that most polar mounts for satellite communication have a fully operating declination axis.

The hour angle and declination look angle equations are given in the appendix. The equations of motion for this type of mount having initial installation errors are beyond the scope of this paper.

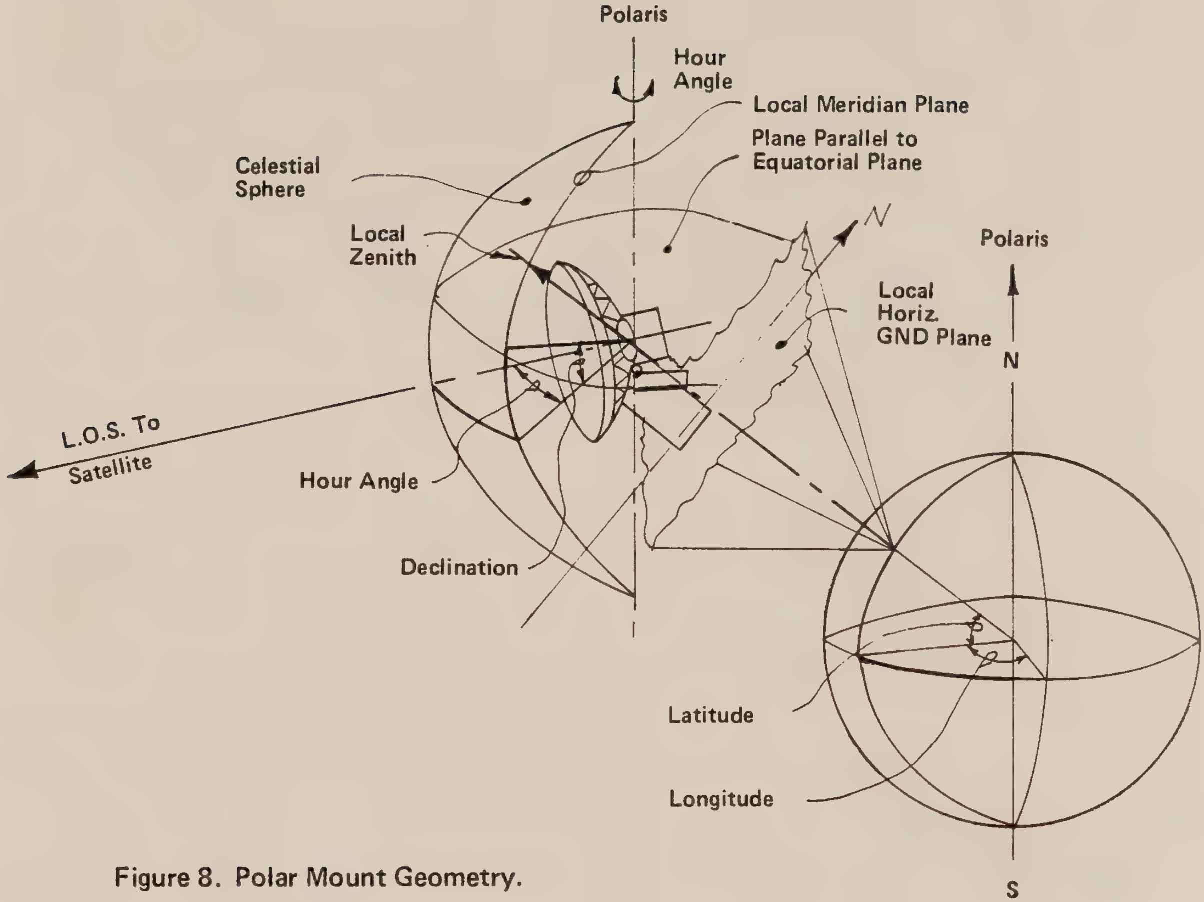
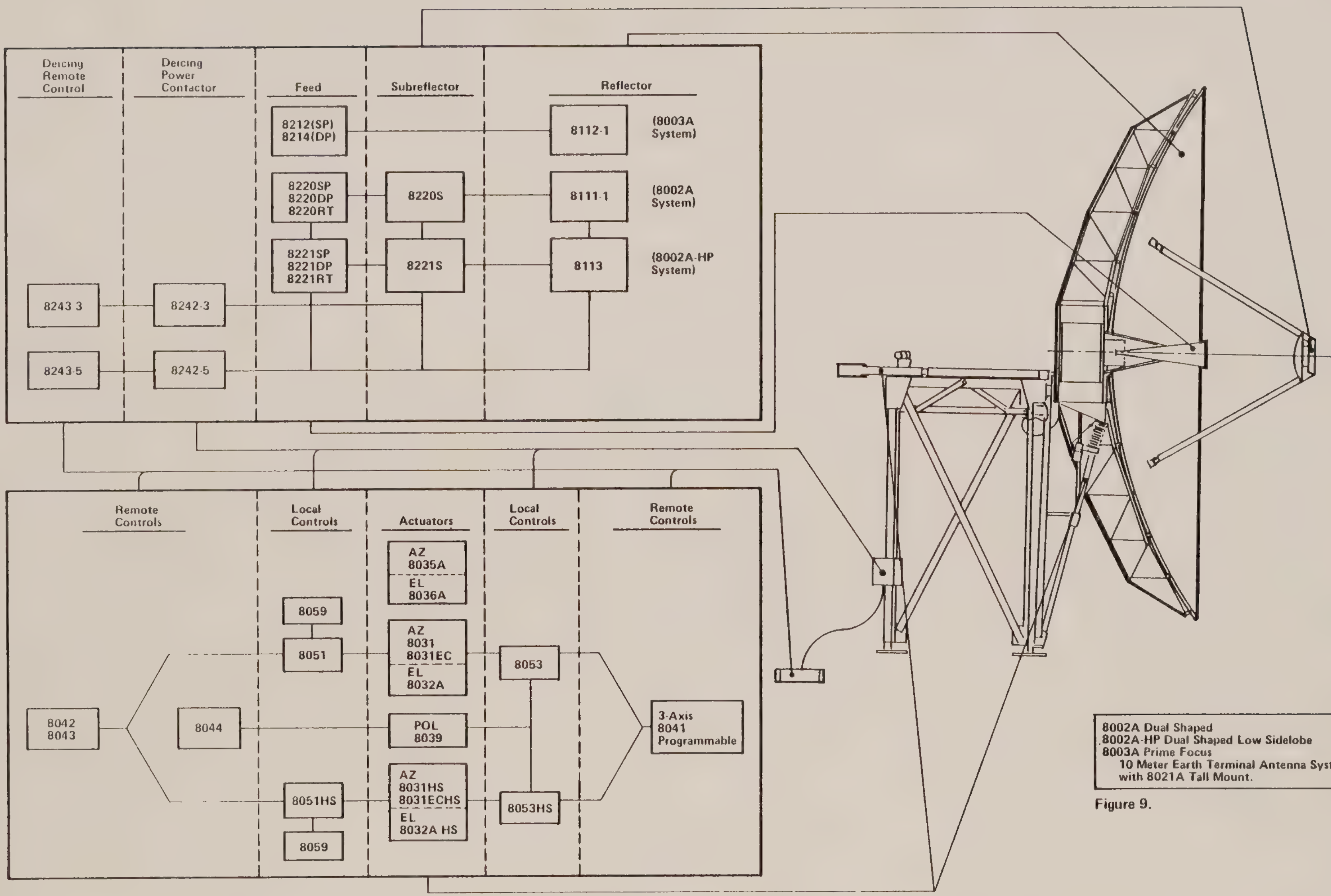



Figure 8. Polar Mount Geometry.

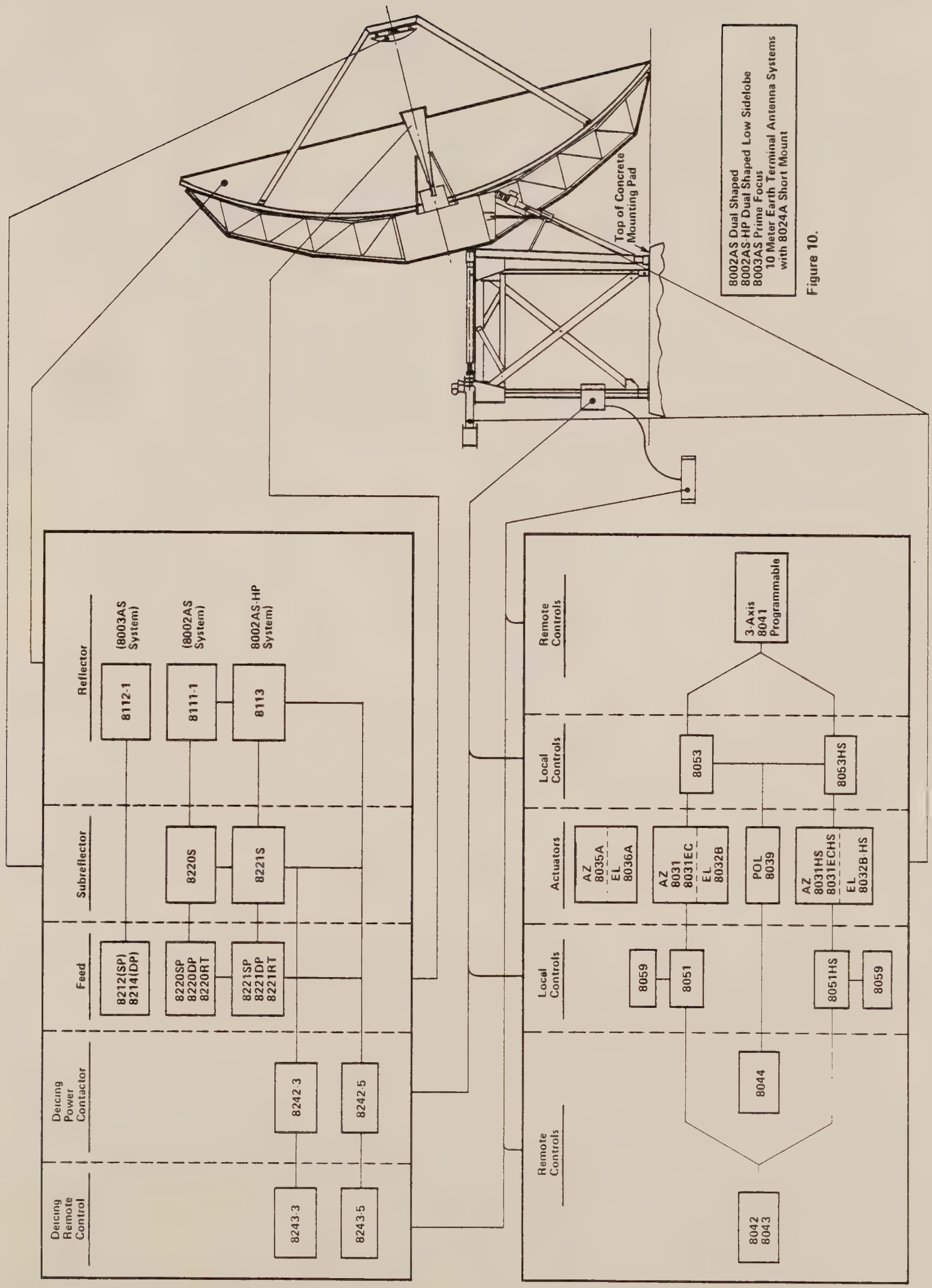
**Motorized Drive Systems and Azimuth Sector Coverage**

Scientific-Atlanta currently produces three different sizes of earth terminals that have motorized positioning systems. These are the Scientific-Atlanta 8007 11 Meter Intelsat Standard B, the Scientific-Atlanta 8001 extreme environment and 8002 Domestic 10 Meter and an extreme environment 5 meter earth terminal. The 8002 10 meter domestic service earth terminal is the backbone system used for broadcast, CATV, and common carrier service here in the U.S. and other countries such as Indonesia. Scientific-Atlanta has developed a large product mix to support this versatile system. Figures 9 and 10 show just the antenna related products. The receiver and transmitter product mix is covered separately. The differences between the two figures is Figure 9 is based on the 8021A standard tall mount and Figure 10 on the 8024A short mount. The tall mount provides about 2-1/2 feet of reflector ground clearance for all elevation angles down to 0 degrees. The 8024A short mount has a lower elevation limit of 15 degrees. Figure 3 gives the minimum and maximum required elevation look angles to satellites between 70° and 135°W longitude for the U.S. To see a 70° satellite only the northwest corner of the state of Washington requires an elevation look angle of 15° or lower. For the 135° satellite an elevation angle of 15° or lower is required in the New England states northeast of a line passing through Baltimore and Buffalo. The rest of the U.S. has minimum elevation look angles greater than 15°, thus the 8024A short mount can be used in the majority of locations.




8002A Dual Shaped
8002A-HP Dual Shaped Low Sidelobe
8003A Prime Focus
10 Meter Earth Terminal Antenna Systems
with 8021A Tall Mount.

Figure 9.




8002AS Dual Shaped
8002AS-HP Dual Shaped Low Sidelobe
8003AS Prime Focus
10 Meter Earth Terminal Antenna Systems
with 8024A Short Mount

Figure 10.

The greatest required azimuth sweep to cover satellites between 99° and 135°W longitude is about 64 degrees and it occurs in Southern California. The standard azimuth coverage of the Scientific-Atlanta 8002 10 Meter Earth Terminal is 110° in two overlapping sectors of 58° each (−3° to +55° either CW or CCW of centerline depending on which rear corner of the mount the azimuth jack assembly is attached). An extended coverage azimuth jack assembly is available (Model 8031EC) which provides 75° continuous coverage (−18° to +57°). With this optional jack all satellites between 99 and 135° can be covered without having to relocate the jack to the opposite corner of the mount.

The standard drive speed of the motorized 10 meter systems is .01°/Sec. Therefore to traverse 64 degrees it takes about 1-3/4 hours. A higher speed version is available (Model 8031ECHS) which will traverse the same angle in 11 minutes. The standard speed system will position the antenna in full survival winds whereas the high speed drives are limited to winds of 80 mph.

## APPENDIX

### Development of Az-El Pointing Angles

Figure 1A is a space view from above the earth showing a particular site in the northern hemisphere and a satellite west of the site. The angle C is the longitudinal difference between the satellite for which az and el look angles are desired and the site.

Figure 1B is a space side view showing the orbital plane of the satellite passing through the equator. Also shown is the local horizontal plane which is titled with respect to the orbital plane thru an angle 90-X, the compliment of the site latitude, X.

The development of az and el look angles may be easily accomplished by projecting the radius vector of the satellite onto the local horizontal plane displaced to the earth center and then translating back from the earth center to the site.

Figure 2A shows the side space view but with the local horizontal plane horizontal and the orbital plane titled by the compliment of site latitude, X. Figure 2B is the orbital projection onto the horizontal plane. Figure 2C is a view standing on the horizontal plane passing through the earth center and looking toward the earth from the local site longitude. The earth and the lower half of the orbital plane are not shown. The titled orbital plane is seen and the radius vector, R from the earth center to the satellite is shown. The longitudinal difference angle, C is shown. The projected radius vector along the local line of longitude in the orbital plane is shown as R cos C. This projection is shown in Figure 2A. The height of the satellite above the horizontal plane is R cos C sin (90—X) or R cos C cos X. The projection of R into the horizontal plane is shown in Figure 3A and is:

$$\sqrt{R^2 - R^2 \cos^2 C \cos^2 X}.$$

Figure 3B shows the translation back to the site through the unity radius of the earth. Thus the local elevation angle, E is:

$$\tan^{-1}\left(\frac{R \cos C \cos(X) - 1}{R\sqrt{1 - \cos^2 C \cos^2 X}}\right).$$

The local azimuth angle is obtained from the orthogonal projections in the horizontal plane shown in Figure 2B. Thus A, local azimuth is:

$$\tan^{-1} (R \sin C) / (R \cos C \sin X).$$

This may be reduced to:

$$A = \tan^{-1} (\tan C) / (\sin X).$$

Elevation may be obtained either in terms of C and X alone or C, X, and A in which case:

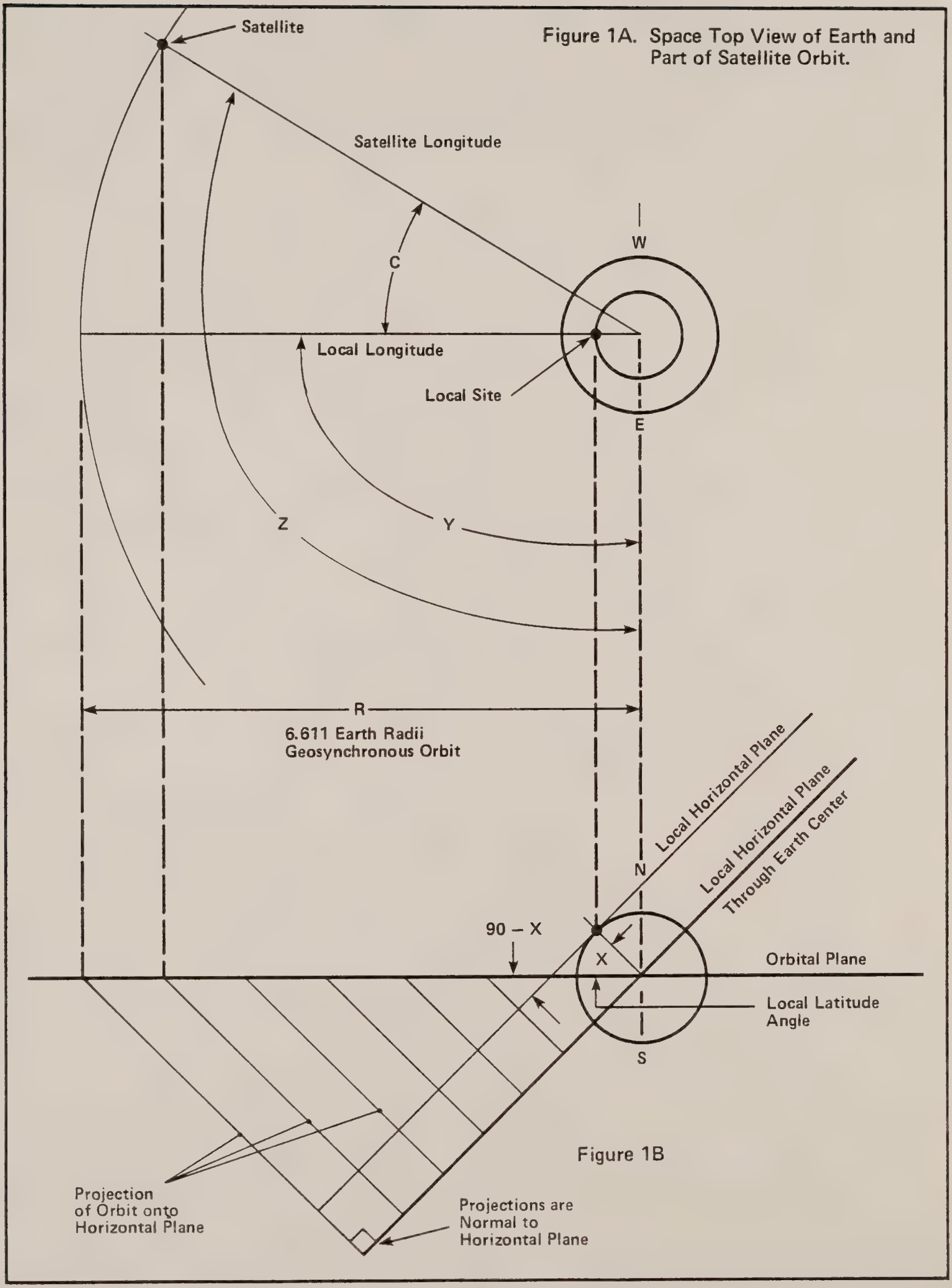
$$E = \tan^{-1} \frac{(\cos C \cos X) - 1/R}{\sin C / \sin A}$$

True azimuth angle is obtained from local azimuth by adding:

$$180^\circ \text{ to } \tan^{-1} \frac{\tan C}{\sin X}$$

For sites in the northern hemisphere. For sites in the southern hemisphere true azimuth is obtained by subtracting:

$$\tan^{-1} \frac{\tan C}{\sin X} \text{ from } 360^\circ.$$



Satellite
Figure 1A. Space Top View of Earth and Part of Satellite Orbit.
Satellite Longitude
C
W
Local Longitude
Local Site
E
Z
Y
R
6.611 Earth Radii
Geosynchronous Orbit
Local Horizontal Plane
Local Horizontal Plane
Through Earth Center
N
90 – X
X
Orbital Plane
Local Latitude
Angle
S
Figure 1B
Projection
of Orbit onto
Horizontal Plane
Projections are
Normal to
Horizontal Plane

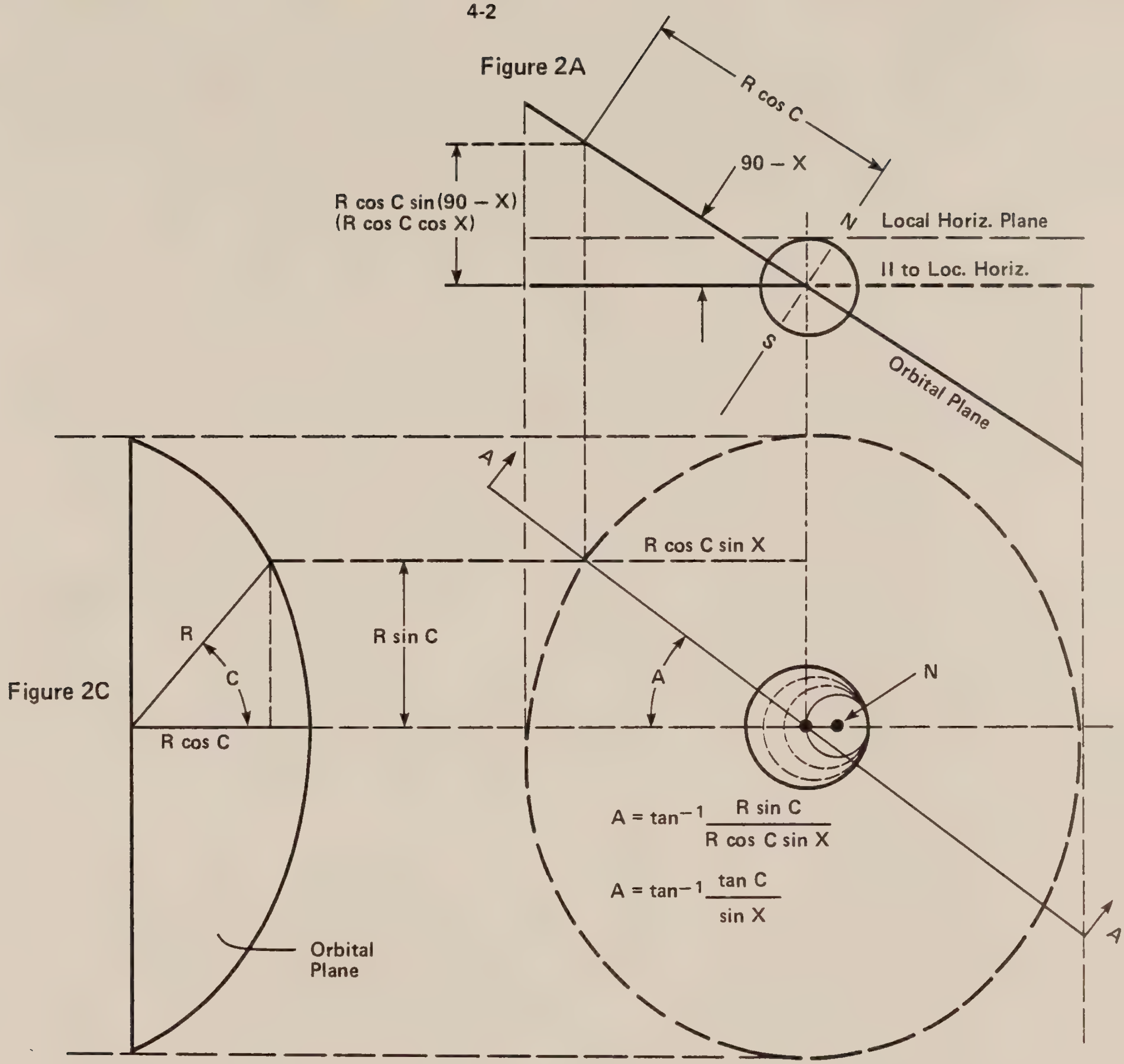



Figure 2B Orbit Projected onto Horizontal Plane

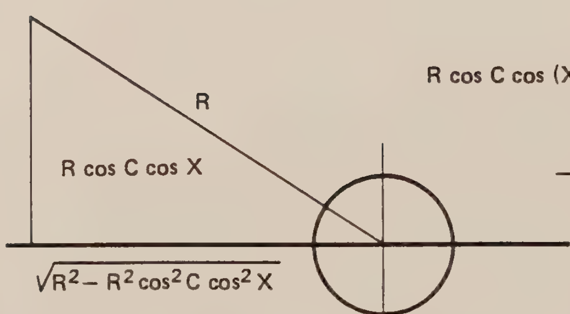



Figure 3A Section A-A of Figure 2B

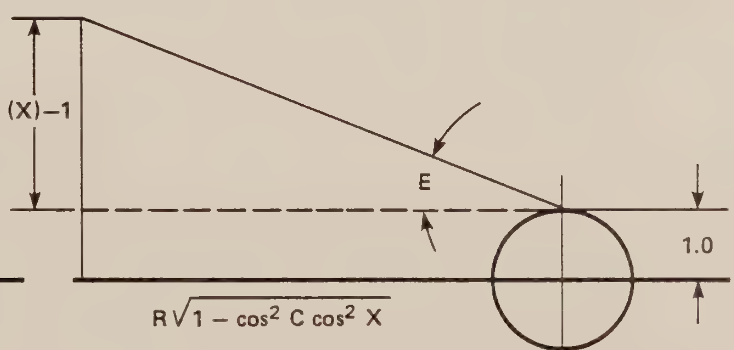



Figure 3B

$$E = \tan^{-1} \frac{R \cos C \cos(X) - 1}{R\sqrt{1 - \cos^2 C \cos^2 X}}$$

$$E = \tan^{-1} \frac{(\cos C \cos X) - 1/R}{\sin C / \sin A}$$

Figure 4A is a plot of local AZ - EL look angles given a site latitude and the difference between satellite and site longitudes. Note that in the northern hemisphere az angles are added to 180° for satellite west of the site and subtracted from 180° for satellites east to obtain true azimuth headings.

Figure 5A defines symbols for subsequent equations.

Figure 6A gives closed form equations for pointing angles for all 3 classes of mounts: Elevation-over-Azimuth, X-Y, and Polarization.

Figure 6A gives A1, mount heading of an X-Y mount knowing X1 (lower axis angle), satellite, and site longitude and site latitude.

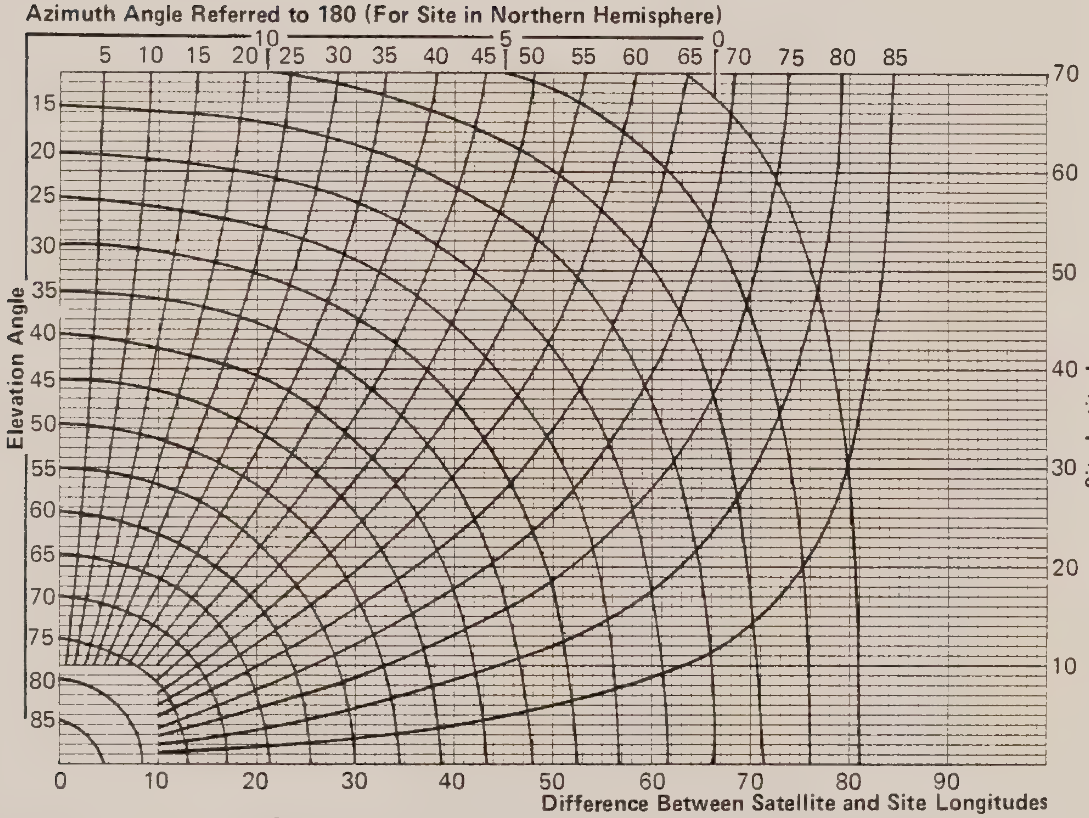



Figure 4A. AZ & EL Angles to Geo-Stationary Satellites

**Figure 5A. Symbol Definitions for AZ/EL, X—Y and Polar Mount Look Angles.**

*let* $X =$ *site latitude*
$Y =$ *site longitude*
$Z =$ *satellite longitude*
$C =$ *satellite longitude — site longitude* $(C = Z - Y)$

*Unique to EL Over AZ Mount*
$A =$ *true local azimuth of satellite*
$E =$ *local elevation of satellite*

*Unique to X—Y Mount*
$A1 =$ *perpendicular true local azimuth of lower axis of X—Y mount*
$A2 = A - A1$
$X1 =$ *lower axis angle with respect to horizontal of X—Y mount*
$Y1 =$ *upper axis angle with respect to peak ascension of X—Y mount*

*Unique to Polar Mount*
$H =$ *hour angle of polar mount with respect to peak ascension measured west-east*
$D =$ *declination of polar mount with respect to peak ascension measured south (in northern hemisphere)*

**Figure 6A. AZ/EL, X—Y and Polar Mount Look Angle Equations.**

*Elevation over Azimuth Look Angles*

$$A\ (AZ) = 180^\circ + \tan^{-1}\left(\frac{\tan C}{\sin X}\right) \quad \text{(Northern Hemisphere)}$$

$$E\ (el.) = -\tan^{-1}\left(\frac{(\cos C \cos X) - 15126}{\sin C / \sin A}\right)$$

*Y Over X Look Angles*

$$A2 = \left(180^\circ + \tan^{-1}\left(\frac{\tan C}{\sin X}\right)\right) - A1$$

$$X1\ (\text{lower axis}) = -\tan^{-1}\left(\frac{\sin A \cos C \cos X - .15126 \sin A}{\sin C \cos A2}\right)$$

$$Y1\ (\text{upper axis}) = \tan^{-1}\left(\tan A2 \cos X1\right)$$

*Declination over Hour Angle (Polar) Look Angles*

$$H\ (\text{hour angle}) = \tan^{-1}\left(\frac{\sin C}{\cos C - .15126 \cos X}\right)$$

$$D\ (\text{declination}) = \tan^{-1}\left(\frac{-.15126 \sin X \sin H}{\sin C}\right)$$

Figure 6A. X-Y Mount Center Line Azimuth as a Function of Satellite and Site Longitude, Site Latitude, Local Satellite Azimuth and Mount X1 Angle.

$$A2 = \cos^{-1}\left(\frac{.15126 \sin A - \sin A \cos C \cos X}{\sin C \tan X1}\right)$$

$$A1 \text{ (mount centerline azimuth)} = A - A2$$

# MOTORIZED ANTENNA DRIVE SYSTEMS

John E. Shepard
Engineer
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## MOTORIZED ANTENNA DRIVE SYSTEMS

### Introduction

To fully use the programming presently available, the earth terminal antenna drive system needs to rapidly and accurately reposition the antenna from satellite-to-satellite in all weather conditions, any time of day or night, with a minimum of personnel. Weather conditions can make operation of a manual system hazardous to impossible. Having two or three men sitting at the site waiting to change the antenna position can make a manual system expensive. Typically, the antenna drive system needs to have the capability of pointing the antenna to all of the desired satellites without mechanical linkage change-overs, as this type of change usually requires time and two to three workers.

A motor drive system needs to meet all of the above conditions and also have other benefits such as being operated by one man, being controlled at the base of the antenna mount eliminating working on a rain-slick or ice-coated structure, being controlled remotely from the equipment shelter, or even controlled remotely from another state.

## FEATURES OF A MOTORIZED ANTENNA DRIVE SYSTEM

### Ease of Control

The system should be ready to move at the flick of a switch, eliminating getting the personnel, tools, ladders, safety belts, and shelter-to-mount communications equipment together. Instead of requiring one man to monitor the signal level and relay information to the two men hand-cranking the system around, one man can operate one to three axes simultaneously and monitor the signal level at the same time.

### All-Weather Operation and Safety

Weather can pose problems in repositioning an antenna. Rain or fog makes footing and hand-holds hazardous, ice and snow can make climbing and manual operation dangerous or impossible. Motor control equipment, however, can be located inside an environmentally controlled equipment shelter, ready to operate day or night, rain or shine.

### Local Control

A control panel having limit indicators, direction of travel indicators, and motor contactor control switches should be mounted in a weatherproof enclosure at the base of the mount. This is a convenient control point for maintenance.

### Remote Control

An additional piece of equipment, termed a remote control unit, could be located inside the equipment shelter. This unit would provide motor contactor control switches, limit indicators, direction of travel indicators and position angle readouts for all desired axes.

The remote control unit allows antenna mount control with personnel safety and comfort in all-weather conditions. It also places the operator near the receive system to monitor the receive signal level while repositioning the antenna.

### Remote/Remote Control

Remote/Remote is a term applied to equipment that will interface with digital remote control equipment to provide antenna system control from a location remote to the antenna site. An example would be Scientific-Atlanta's Model 8041. This unit can be located in the equipment shelter and provide position control, position angle readout, direction of travel indicators and limit indicators. This unit also provides eight programmable satellite position memories. This allows presetting of the azimuth, elevation, and polarization coordinates for up to eight satellites.

Repositioning from one satellite to another consists of selecting the appropriate position number and depressing the "START" switch. When interfaced with digital remote control equipment, the Model 8041 provides rapid and accurate repositioning, and monitoring of all functions from both the equipment shelter and any remote location chosen by the customer.

**Limit Switches** The desirability of limit switches is obvious. They protect the antenna, antenna mount, and drive system from damage by mechanical interference. A not too obvious point to look for in limit switches is the ability to stop the system during any type of control system failure. For instance, a limit switch that interrupts the control signal to a solid-state relay will have no effect if the secondary of the solid-state shorts. The system will drive past the limit may cause physical damage.

The control unit should have limit-of-travel indicators for each limit switch.

**Position Indicators** With most receive systems, both the azimuth and elevation axes must be within 0.7° to 1.5° of the satellite position to see any signal above the noise level. Without a position readout, the usual procedure used to locate a satellite is to point the antenna in the general direction of the satellite and make an azimuth sweep, raise elevation 0.5° and make another azimuth sweep and to repeat this process until the signal is located.

An aid in minimizing the time required to acquire a satellite is an accurate readout of the antenna position angle in each axis. The antenna look angles for a given satellite are readily calculated for both the azimuth and elevation axes. The antenna is then positioned to the calculated angles. If the antenna requires peaking from the calculated angles, the final readouts can be recorded for future use.

There are three common types of readout devices. A counter is the simplest. It is usually geared directly to the drive mechanism and cannot be seen or used remotely. The counter numbers are usually not a direct function of angle and conversion tables must be used to determine the position angles.

A synchro package is more complex and can be monitored at the equipment shelter. The disadvantages are its high cost and the requirement of an A/D converter if the control point is to be connected by digital remote equipment.

The third type uses a high linearity potentiometer and a well regulated voltage supply as a data sending unit. The potentiometer is mounted directly to the axis of rotation on the antenna drive system. This arrangement gives a direct relationship between position angle and wiper voltage. The readout would be a digital panel meter. This approach is inexpensive and has very good accuracy and repeatability. The data voltage can be scaled with resistors and applied directly to digital remote control equipment for remote monitoring.

## MOTOR DRIVE SYSTEM CONSIDERATIONS

### Motor Type

Single phase motors require start windings to have adequate starting torque. Since the start windings draw high currents, their duty cycle is generally limited to no more than two starts a minute. This is a big disadvantage while trying to jog an antenna to the beam peak. Another disadvantage is the RFI created by the start windings being switched out of the circuit when the motor gets up to speed.

Three-phase motors are generally selected for this type of application. They do not have start windings or the associated RFI. Three-phase motors will withstand constant jogging. They are also available in a wide range of horsepower, voltage, and frequency choices.

### Motor Control

Electro-mechanical relays are a reliable means of controlling motors. They offer easy maintenance, convenient direction reversal, and positive opening of the ac supply to the motors. Their disadvantage is the RFI generated by abruptly breaking the line to an inductive load.

Solid-state relays, SSR's avoid the RFI generation by switching on at a zero voltage crossover point and switching off at a zero current crossover point. The disadvantages with SSR's are that seven are required per axis and a secondary short could place a short across the ac supply or circumvent a limit switch.

A combination of SSR's and electro-mechanical relays has the advantages of both types without the disadvantages.

By placing two SSR's in series with two of the three output lines of an electro-mechanical relay, RFI is suppressed, the relay contacts last much longer, a shorted SSR will not cause a supply line short, and the electro-mechanical relay ensures a positive opening when a limit switch is opened.

### Repositioning Time

The time required to reposition the antenna from one satellite to another satellite is a critical factor in using programming from multiple satellites. The factors involved in repositioning time would include: the satellite spacing, location of the antenna, antenna drive speed, and mechanical linkage change-overs if required. The satellite spacing factor is obvious, repositioning time between widely separated satellites would be greater than between adjacent satellites. The subtended azimuth angle as a function of antenna location is shown in Figure 1 for satellites at the extremes of the present arc, WESTAR I at 99° longitude and SATCOM I at 135° longitude. The southwestern region of the contiguous U.S. would require the greatest azimuth coverage while the eastern U.S. would require the least azimuth coverage. Also shown in Figure 1 is the time required to reposition the antenna from end-to-end of the present arc of satellites using a Scientific-Atlanta Series 8050HS High Speed Drive. This drive system has a 0.1°/second rate. The times shown in Figure 1 also assume a drive system that has continuous coverage of the desired arc without having to stop and change some mechanical linkage. Drive systems with other rates would require times proportional to Figure 1. For example a 0.01°/second rate would require one hundred and eight minutes in southern California. The time to make mechanical linkage changeovers would also have to be considered in some systems.

The combination of Scientific-Atlanta's Model 8041 Programmable Remote Control Unit and the Model 8053HS High Speed Drives results in a system that has a minimum repositioning time due to the drive speed and continuous coverage, the ability to be preprogrammed for up to eight satellite coordinates, and the remote/remote control features greatly reduce the logistics of repositioning.

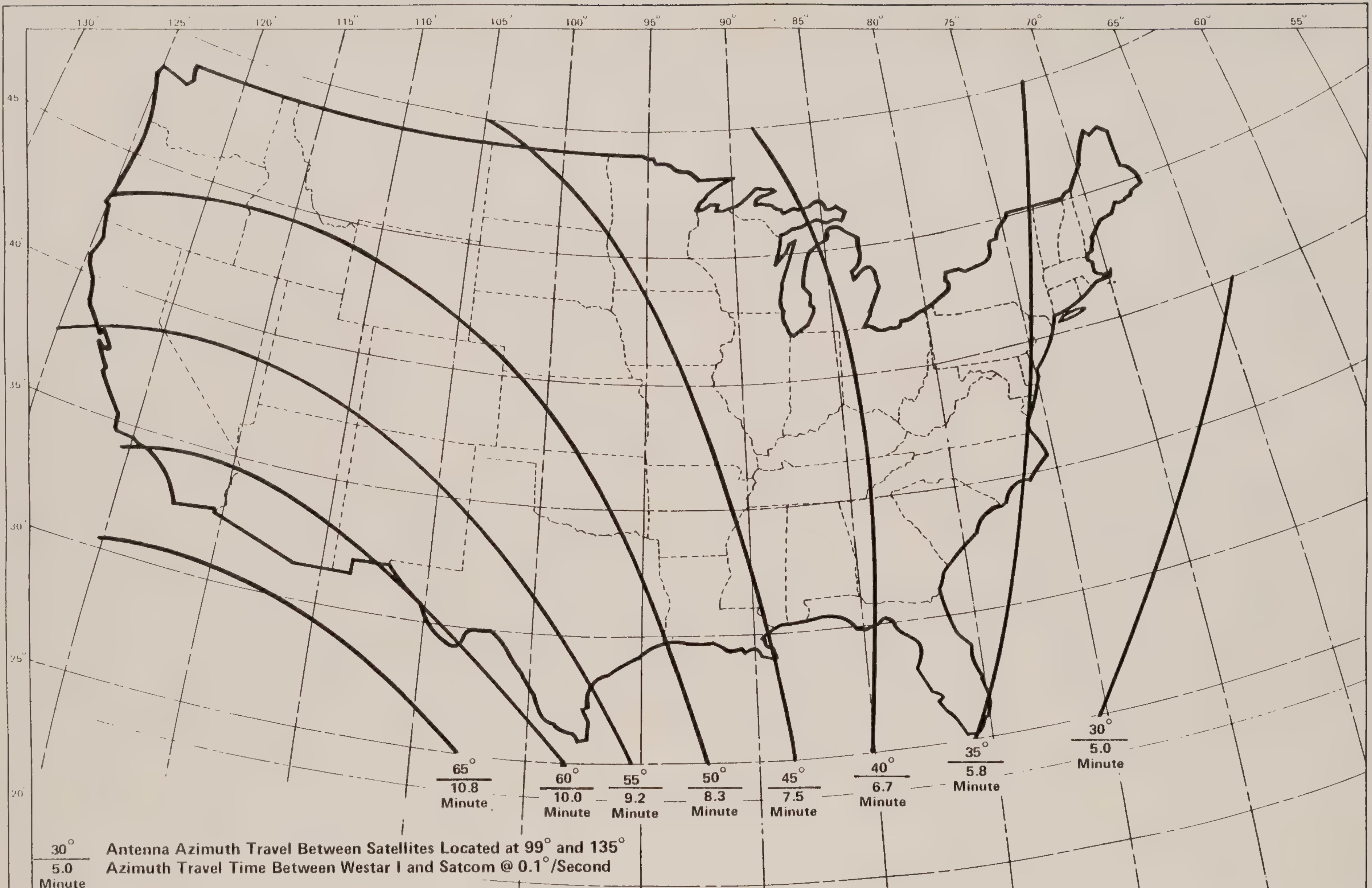

130° 125° 120° 115° 110° 105° 100° 95° 90° 85° 80° 75° 70° 65° 60° 55°
45 40 35 30 25 20
65° 10.8 Minute
60° 10.0 Minute
55° 9.2 Minute
50° 8.3 Minute
45° 7.5 Minute
40° 6.7 Minute
35° 5.8 Minute
30° 5.0 Minute
30° 5.0 Minute
Antenna Azimuth Travel Between Satellites Located at 99° and 135°
Azimuth Travel Time Between Westar I and Satcom @ 0.1°/Second

Figure 1.

# ANTENNA DEICING

John E. Shepard
Engineer
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## ANTENNA DEICING

Ice or snow accumulation on an antenna feed, subreflector, or reflector can cause undesirable effects on antenna performance. An eighth of an inch or less of ice on a feed radome can cause a return loss of 8 to 11 dB and a transmission loss of 0.3 to 0.7 dB in the 4/6 GHz band and will result in a return loss of approximately 6 dB and a transmission loss of approximately 1.5 dB in the 12/14 GHz band. The transmission loss is mainly due to reflection caused by the dielectric properties of the ice.

Ice or snow on the subreflector could cause the effective surface tolerance to increase resulting in increased wide angle radiation caused by scattering. This effect increases with increasing frequency.

Snow or ice accumulation on a reflector can have effects ranging from an apparent increase in surface tolerance to an apparent change in shape of the reflector itself. The result of either case is a reduction in signal level. The reduction can vary from a few tenths of a dB to several dB.

### Deicing Control Equipment

Deicing control equipment can be separated into three groups. Local manual control, remote manual control, and remote automatic control.

### Local Manual Control

The control can be a simple manually operated on/off switch located at the antenna mount. The low initial cost of this approach is an advantage. See Figure 1.

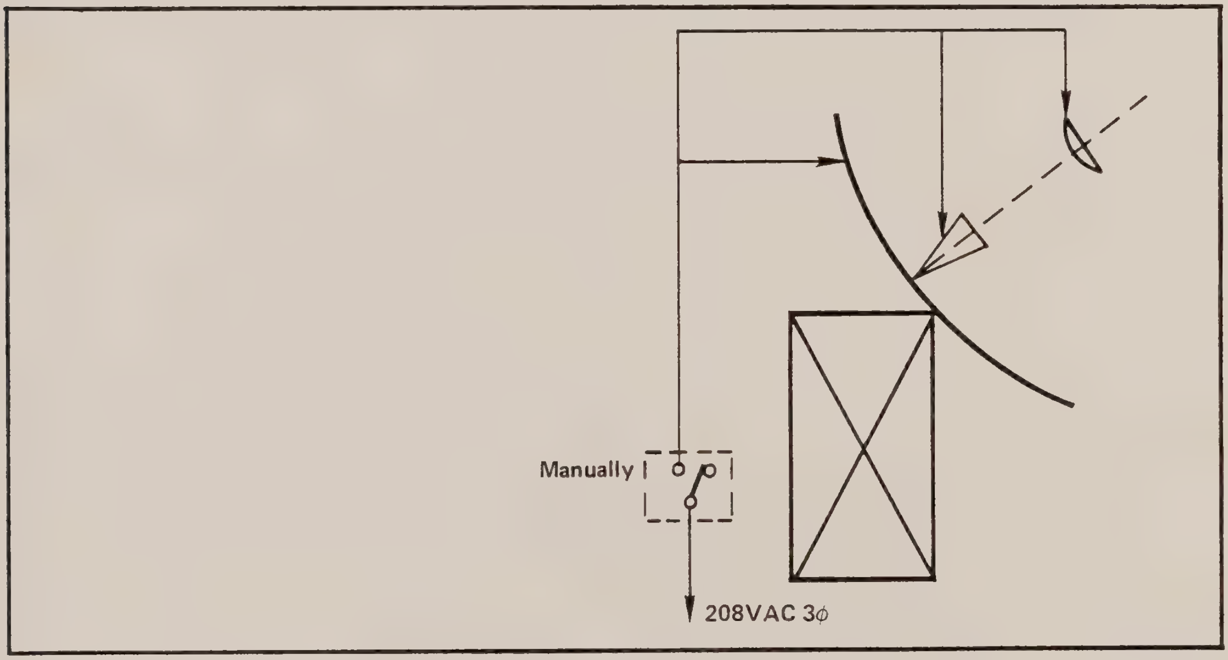



Figure 1. Local Manual Control

### Remote Manual Control

Remote control consists of ac contactors located at the mount and a control unit located in the equipment shelter. The control unit houses switches to supply control signals to the ac contactors. Upon command, the ac contactors apply power to the heaters. The disadvantage of a manual system is the necessity of having someone at the site to turn the equipment on whenever snow or icing conditions occur. See Figure 2.

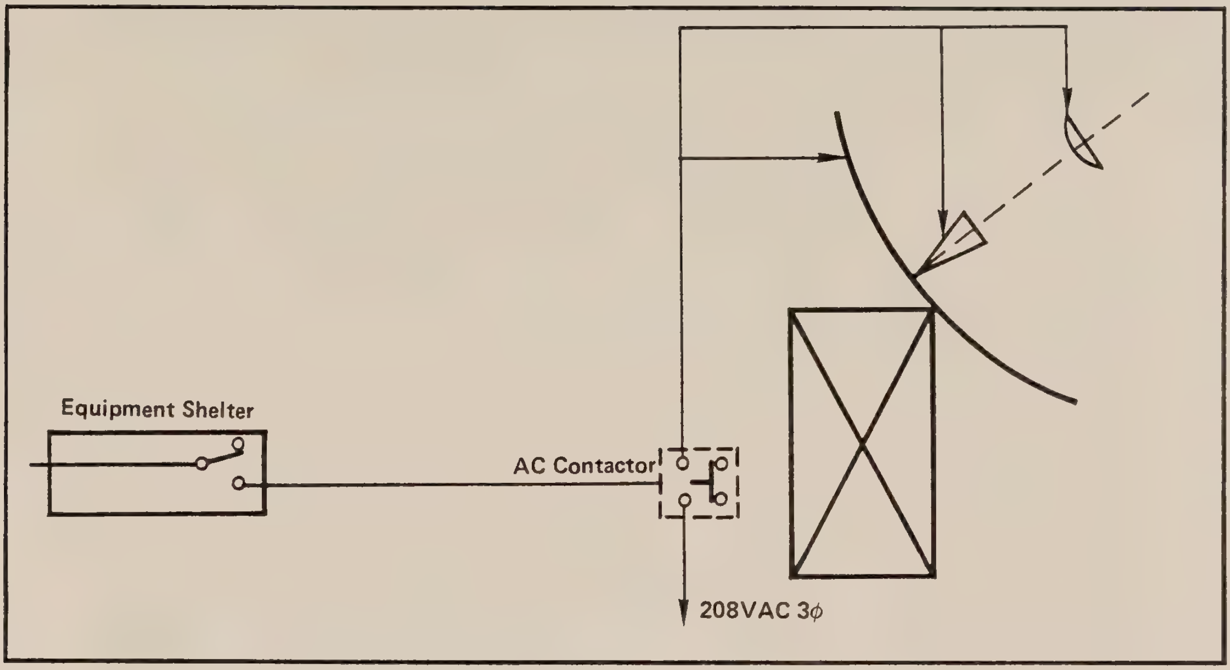



Figure 2. Remote Manual Control

**Automatic Control Equipment**

Automatic control equipment generally consists of a control unit located in the shelter and a sensor located on the antenna. The control unit is turned on but does not supply a control signal to the heater power contactors unless the sensor is armed by a combination of both precipitation and freezing temperatures. An absence of either precipitation or freezing temperatures disarms the sensor and leaves the control unit in a "standby" mode. A system of this type does not require personnel at the site and, also, has minimum power consumption. Automatic control equipment can also be monitored and controlled by digital control equipment from a control point remote to the antenna site. See Figure 3.

**Deicing Requirements**

Deicing requirements vary drastically with location. In an area with moderate snow and ice conditions, feed and subreflector deicing would suffice. In an area with dry snow and occasional icing conditions, the feed, subreflector, and the bottom half of the main reflector would require deicing. In an area with wet snow and frequent icing conditions, feed, subreflector and full reflector deicing may be required. Since conditions can vary drastically in a matter of miles, generalized weather maps are not detailed enough to determine deicing requirements. Local weather bureaus are a better source for the required information.

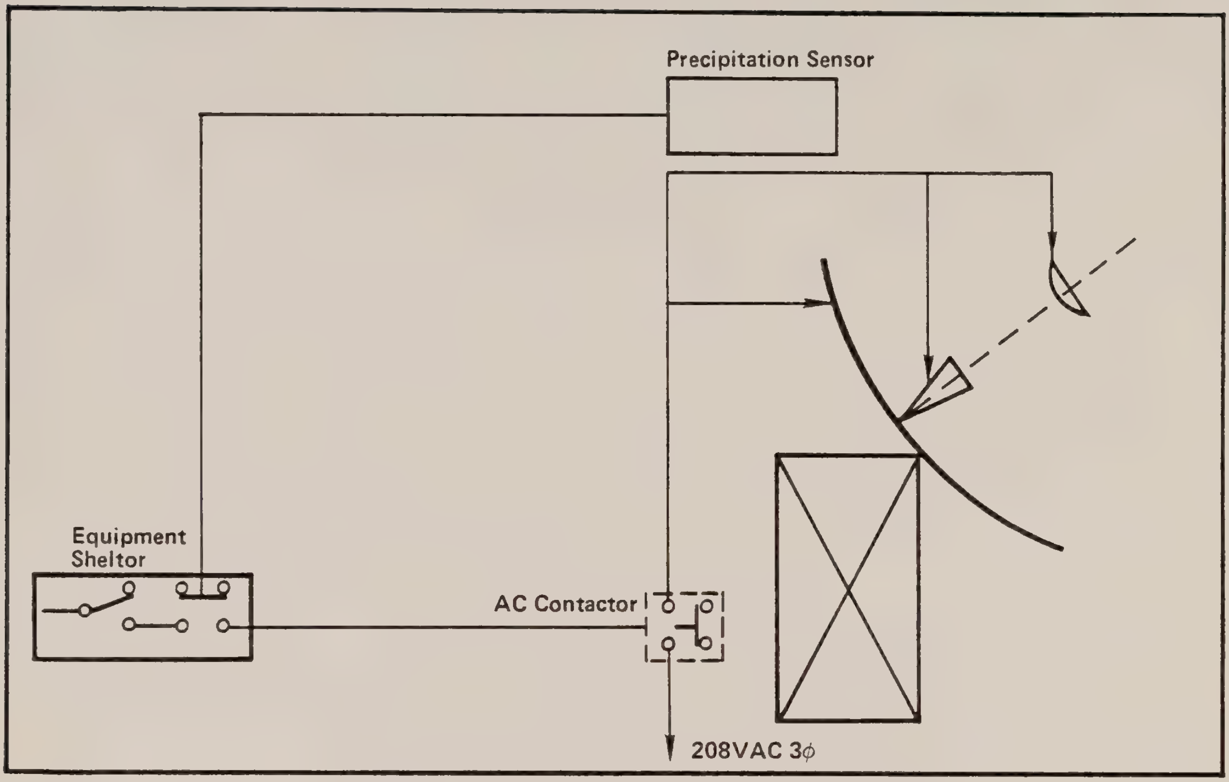



Figure 3. Automatic Control

# COMPARISON of PERFORMANCE CRITERIA of 5 and 10 METER EARTH STATIONS

Jim Hart
Project Manager
Cable Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

# COMPARISON OF PERFORMANCE CRITERIA OF FIVE and TEN METER EARTH TERMINALS

**ABSTRACT** Geostationary satellite communications links have found wide use in CATV during the past two years. Until recently, only 10 meter diameter antennas have been employed for domestic video receive terminals. Careful study and consideration of all requirements of the communications industry has now shown that smaller diameter antennas of 4.5 and 5 meters will satisfy requirements for a percentage of the 48 contiguous states. Consequently, the FCC has stated that they will approve those terminals which employ smaller antennas if the applicant outlines his requirements and gives adequate proof that those requirements are met. This paper is a comparative analysis of 5 and 10 meter antenna receive terminals and shows tradeoffs which must be considered for various locations in the 48 contiguous states.

## 1.0 Introduction

This paper is a presentation of operational characteristics of 5 and 10 meter earth terminals in graphic form. Supporting derivations are given where it was felt that a greater depth of understanding the data would result. Certain assumptions were made on characteristics which have negligible effects on the results. These assumptions are carefully outlined in each section. The last sections deal with the summation of the earth terminal degradation and that due to the CATV system. The overall performance of the headend and distribution system is the important aspect for cable operators. The paper is developed in a sequence which should be easy to follow step by step. Taking information out of context without understanding the foundation presented in previous sections is not recommended in this case.

## 2.0 Overall Considerations

Basically the requirement of an overall link is a quality picture at the final destination – the viewer's home. Many factors affect the ultimate picture quality. Generally, the downlink and CATV distribution system have the greatest impact on signal quality. This, of course, assumes that the studio quality is adequate. The purpose of this paper is not to analyze link degradations but to compare typical 5 and 10 meter receive terminals and their performance in a complete system. To accomplish this task without getting deeply involved in system analysis, a set of degradation allowances which are presently under consideration by the FCC and others will be utilized. Figure 1 is a summary of these allowances. First, the downlink is analyzed under clear sky conditions. The basic allowance of 3.65 dB is then subtracted from the main IF carrier-to-noise ratio (C/N), and the result is considered a worse case condition. This worse case condition will be accepted if the C/N falls equal to or above the receiver objective threshold (threshold being defined as the point where S/N ratio is worse by 1 dB than the projected asymptote at high C/N). This allowance and its prescribed use is not to be considered final and is subject to change, but it provides a convenient method for this comparison.

FCC Recommended Satellite Link Degradations

| Parameter | Nominal (dB) | Random (dB) |
|---|---|---|
| EIRP | 0 | 0.15 |
| Satellite Degradation | 0.4 | 0.4 |
| Atmospheric Absorption | 0.1 | 0.1 |
| Polarization Loss | 0.1 | 0.1 |
| Rain Attenuation | 0 | 0.2 (1) |
| Pointing Error | 0.3 | 0 |
| Wind | 0 | 0.4 |
| Antenna Gain | 0 | 0.2 |
| Earth Station Degradation | 0 | 0.35 |
| Interference | 1.0 | 0 (2) |
| FM Threshold Margin | 1.0 | 0 |
| | 2.9 | 0.75 (3) |

(1) Or as appropriate for given location
(2) Or Calculation
(3) Combined on a Root Sum Square basis

Figure 1

## 3.0 Downlink Considerations

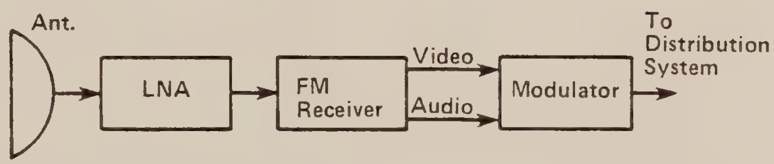
### 3.1 System Noise Temperature

Figure 2a is a simplified block diagram of a receive terminal. Figure 2b assigns gain and noise temperature quantities to each contributing element of the terminal.

System noise temperature at the antenna flange is given by:

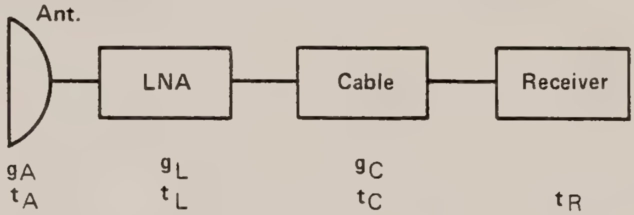
$$t_S = t_A + t_L + t_C/g_L + t_R/(g_L g_C)$$

where
$t_S$ = System noise temperature at antenna flange °K
$t_A$ = Antenna noise temperature °K
$t_L$ = LNA noise temperature °K
$t_C$ = LNA to receiver cable noise temperature °K
$t_R$ = Receiver noise temperature °K
$g_L$ = LNA gain ratio
$g_C$ = Cable gain ratio




Receive-Only Earth Terminal

Figure 2A




Gain-Noise Temperature Diagram

Figure 2B

Figure 3a presents the system noise temperature of a Scientific-Atlanta 5 meter system versus LNA noise figure. The following typical variables were assumed:

Cable Loss = 6 dB (200 feet)
LNA Gain = 47 dB (Minimum)
Receiver NF = 12 dB
Antenna $t_A$ = 20°K (30° Elevation)

Figure 3b is the same data for a 10 meter system assuming:

Cable Loss = 6 dB
LNA Gain = 47 dB
Receiver NF = 12 dB
Antenna $t_A$ = 28°K

The overall noise temperature is affected only a very small amount by variations in these assumed quantities at different sites, and the preamplifier is the dominant factor.

The small difference in the 5 and 10 meter cases is due to the type feed utilized and the sidelobe patterns of the two antennas.

The 10 meter antenna utilizes a focal-point feed to achieve a superior side-lobe pattern at the expense of greater loss in the waveguide run to the feed. Optimization for interference rejection is desirable because, as will be shown, gain in the 10 meter case is available for tradeoff.

### 3.2 Receive System G/T

The receive system G/T is given by:

$$G/T = G_A - 10 \log t_S$$

where G/T = Receive system Gain/Noise Temp in dB/°K
$G_A$ = Antenna gain at flange in dB
$t_S$ = Flange system noise temperature in °K

Figures 4a and 4b show the G/T curves for the 5 and 10 meter case versus LNA noise figure. Assumptions in addition to those in Section 3.1 were:

$G_A$ = 44.5 dB (5 Meter)
$G_A$ = 50.2 dB (10 Meter)

Due to nearly equivalent noise temperatures for the two antennas, the G/T difference is almost entirely related to the gain difference.

G/T is a quality factor which is directly related to performance and cost of video earth terminals.

## 3.3 Main IF Carrier-to-Noise Ratio

The next important parameter is the receiver IF carrier-to-noise ratio (C/N). Noise of an FM link can be divided into two categories for understanding the process even though both are derived from the same source — thermal noise.

First, there is carrier power to noise power density given by:

$$(C/N_o) = EIRP - Lp + G/T - K$$

where EIRP = Effective isotropic radiated power dBw
Lp = Path loss in dB
G/T = System G/T in dB/°K
K = Boltzmanns constant (-168.6 dBw/MHz/°K)

This $(C/N_o)$ affects (S/N)v on a one-for-one basis when the link is operated well above threshold, and

$$(C/N) = (C/N_o) - 10 \log b_{IF}$$

where $b_{IF}$ = Effective main IF noise bandwidth in MHz

This (C/N) determines the threshold of the receiver.

Path loss is given approximately by:

$$Lp = 96.6 + 20 \log f + 20 \log d$$

where f = Frequency in GHz
d = Distance in miles

Secondly, when an FM system is operated near or below threshold, the peaks of noise reduce the instantaneous sum of signal-plus-noise to near zero. Under these conditions, the FM discriminator becomes unable to determine the instantaneous phase of the carrier, and impulse noise appears in the detected signal. This results in a greater than one-for-one variation in S/N and the characteristics of this impulse noise are different than that of the previously demodulated thermal noise. The impulse noise appears very rapidly below threshold, and it causes serious degradation to picture and audio quality. For this reason, it is necessary to operate FM systems above threshold for quality performance.

Figures 5a and 5b give the C/N ratio for a clear sky. Assumptions in addition to those in Sections 3.1 and 3.2 were:

$$L_p = 196.0 \text{ dB}$$
$$b_{IF} = 39 \text{ MHz}$$

The IF filter is an INTELSAT 36 MHz type. An improvement in the margin against threshold of 0.8 dB can be obtained for those marginal cases by utilization of an INTELSAT 30 MHz filter; however, no benefit in the ultimate S/N results in this move since S/N ratio is not a function of IF bandwidth when operating above threshold as will be later shown.

Figures 6a and 6b show the C/N ratios including the 3.65 dB degradation of Figure 1. Two threshold lines are shown. The upper line represents a standard Scientific-Atlanta 414 receiver. The lower line is the same receiver with threshold extension included. Again it must be remembered that threshold extension does not improve the ultimate S/N ratio except when operating down near and below threshold. This will be shown in later S/N curves.

**3.4 Threshold**

Figures 7a and 7b give the threshold characteristics of a Scientific-Atlanta 414 receiver with and without threshold extension. In each case, threshold is defined as the C/N where the S/N curve departs 1 dB from the high C/N asymptote. Note that this occurs at 9.3 dB for no extension and 7.3 dB with extension. Also note that S/N at these points are 47 dB and 45 dB respectively.

Threshold extension has carried threshold to such a low C/N that S/N ratio is becoming the limiting factor. Most CATV systems are operated with headend S/N of greater than 45 dB; therefore, further improvement in C/N performance by reducing bandwidth must be done keeping in mind that the 45 dB S/N will drop even lower. This may or may not be desirable for a particular CATV cascade. Curves to follow will aid in making this decision.

**3.5 Video Signal-to-Noise Ratio**

The video signal-to-noise ratio (S/N)v is given by:

$$(S/N)_v = \frac{C}{N_o}\left[\frac{12(\Delta Fs)^2}{b_n^3}\right]$$

where C = Carrier power in watts

$N_o$ = Noise power density at that point in the receiver where C is measured

= $K\ t_s$ in Watts/MHz

K = Boltzmann's constant ($1.3806 \times 10^{-17}$ W/MHz/°K)

$t_s$ = System operating noise temperature referred to that point in the system where C is measured in°K

$\Delta F_s$ = Half the peak-to-peak deviation produced by that part of the video waveform defined to be the signal in MHz

$b_n$ = Noise bandwidth of the baseband filter function representing the combination of the de-emphasis network, measurement bandlimiting filter, and weighting network with respect to triangular noise in MHz

= 1.574 MHz for CCIR weighted

Figures 8a and 8b give the $(S/N)_v$ for the 5 and 10 meter cases clear sky. The assumptions are as previously stated in addition to:

$$\Delta F_s = (.714)\ (10.75\ \text{MHz})$$
$$= 7.68\ \text{MHz}$$

Video systems presently in use in this country are using this deviation. Note that two curves exist on Figure 8A. The dotted case shows the effect of threshold extension. Note that no change occurs above threshold. It is true, however, that the small change which does occur near threshold is of extreme importance since impulse noise is removed. Threshold extension has no use in the 10 meter case under these assumed conditions as shown in Figure 8b.

Figures 9a and 9b give the $(S/N)_v$ after application of the 3.65 dB degrading factor to C/N. Note that above threshold the curves have simply moved down by 3.65 dB, but at and below threshold the effect is much greater due to impulse noise. In these curves the advantage of threshold extension can be seen even in the 10 meter case to a small degree.

**3.6 Audio Threshold**

Figure 10 gives the audio threshold characteristics of the Scientific-Atlanta 414 receiver. The unweighted audio $(S/N)_A$ is shown versus main IF C/N. Note that audio threshold occurs at about 7.6 dB (C/N). Assumptions are:

Subcarrier on Carrier Deviation = 2 MHz Peak
1 kHz Test Tone on Subcarrier = 75 kHz Peak

It is important to note that the deviations of video and audio are well chosen since audio thresholds at a near equal C/N as video with threshold extension. Any reduction in the audio deviation rules out any use of threshold extension since it has little effect upon audio threshold in this case.

**3.7 Audio Signal-to-Noise**

Figures 11a and 11b give $(S/N)_A$ for the 5 and 10 meter cases. These curves were derived from Figures 5 and 10.

Figures 12a and 12b give $(S/N)_A$ for the 5 and 10 meter cases including the 3.65 degrading factor. These curves were derived from Figures 6 and 10. No mention is made of threshold extension since it has been shown that it affects $(S/N)_A$ very little.

**3.8 Overall CATV System Video Performance**

This section deals with the heart of the matter. What counts is the result at the home. The earth terminal and CATV system share in the overall degradation.

How is the CCIR $(S/N)_V$ at the output of the headend FM receiver related to the NCTA (S/N) which would produce the same quality picture if the noise source were thermal noise in the distribution system? The best thing to say is that they are essentially equivalent. However, if we are considering an objective CCIR measurement at the output of an ideal home receiver(as in the case treated by Straus[2]) and are concerned about tenths of a dB, the answer is that

$$\text{Equivalent NCTA} = \text{Headend } (S/N)_V + 0.3 \text{ dB}$$

because as shown by Straus

$$\text{Equivalent NCTA} = \text{Home Rcvr CCIR } (S/N)_V + 0.2 \text{ dB},$$

and

$$\text{Home Rcvr CCIR } (S/N)_V = \text{Headend } (S/N)_V + 0.1 \text{ dB}$$

The latter relation results from the effect of the rolloff of the Nyquist filter in the ideal home receiver on de-emphasized triangular noise between 4 and 4.2 MHz.

Figure 13a shows the combined noise of the headend receiver and the distribution white noise. It is important to note again that receiver baseband S/N of 45 dB (which results at threshold with threshold extension) will have an impact on most CATV systems — especially those which are operating at NCTA (S/N) of 45 dB and better.

**3.9 Overall CATV System Audio Performance**

Figure 13b gives a curve similar to 13a for the overall audio performance. The earth terminal noise was power added to the CATV distribution system noise contribution to obtain the overall result. The audio (S/N) for the CATV system is given by:

$$(S/N)_A = \frac{C}{N_o}\left[\frac{3}{2}\,\frac{\Delta F_A^{\,2}}{b_{NA}^{\,3}}\right]$$

where $C$ = audio subcarrier power in watts
$N_O$ = noise power density in watts/MHz
$\Delta F_A$ = half the audio peak-to-peak deviation in MHz
$b_{NA}$ = triangular noise bandwidth of baseband response function for 75 $\mu$s de-emphasis with 1 kHz crossover with ideal rectangular 15 kHz band-limiting filter
= $5.82 \times 10^{-3}$ MHz*

The assumption for Figure 13b was:

$$\Delta F_A = .025 \text{ MHz}$$

Also it was assumed that the aural subcarrier was run at −15 dB with respect to the video carrier on the CATV system.

It can be noted in Figure 13b that almost all the degradation of audio occurs in the satellite link, but the quality is still quite good.

## 4.0 Conclusion

The quality of a video link by satellite is governed by many factors. It is important for the individual operator to consider his requirement and buy the system best suited for his needs. Careful consideration must be given to threshold and the overall performance desired. Other considerations such as terrestrial interference must be looked at on an individual basis.

## 5.0 Acknowledgment

My sincere appreciation is expressed to Dr. Larry Clayton, Heinz Wegener, and Elias Livaditis for their invaluable support in writing this paper.

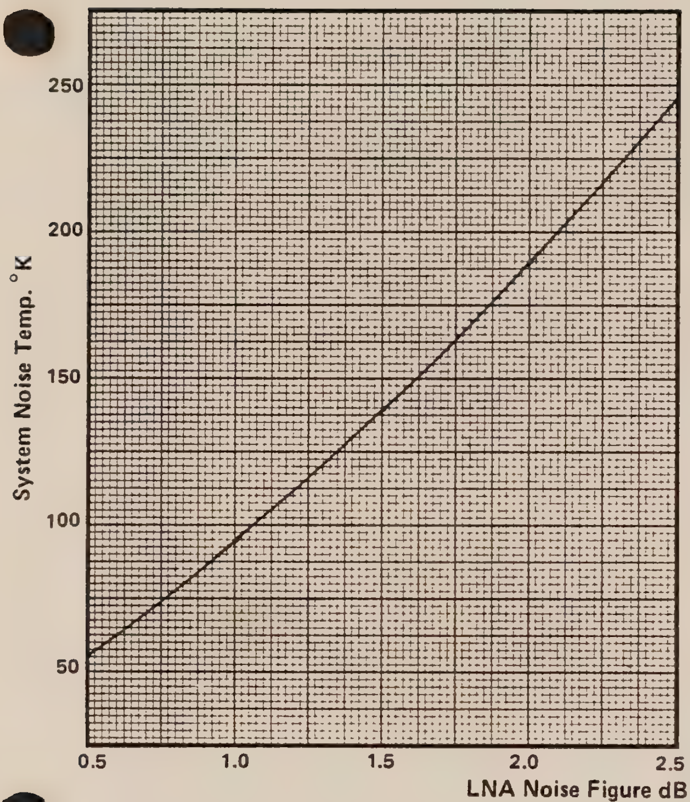
## References

1. L. Clayton, "FM Television Signal-to-Noise Ratio" IEEE Transactions on Cable Television, October 1976, p. 25-30.
2. T.M. Straus, "The Relationship Between the NCTA, EIA, and CCIR Definitions of Signal-to-Noise Ratio" NCTA 1974, p. 58-63.

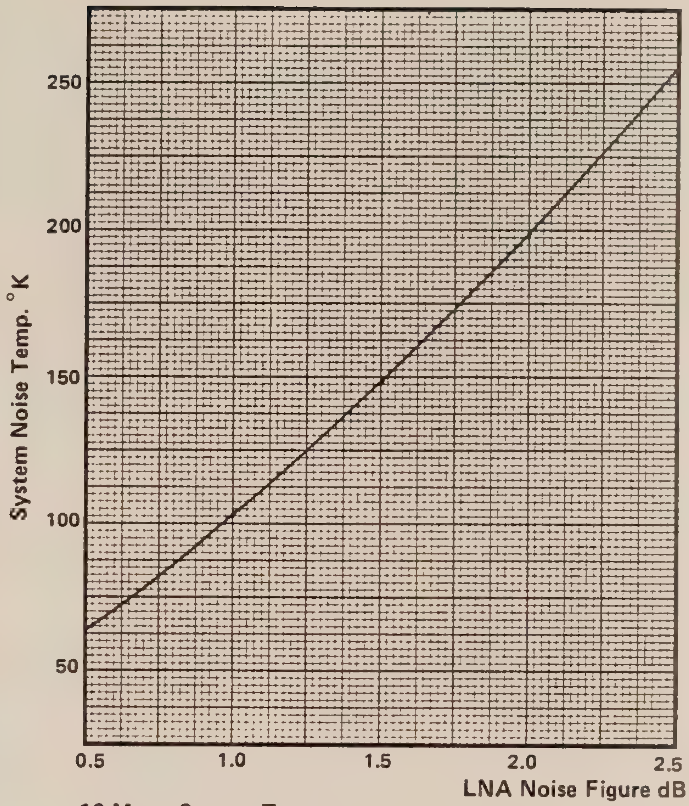
*This noise bandwidth corresponds to a de-emphasis advantage of:

$$30 \log (15 \text{ kHz}/5.82 \text{ kHz}) = 12.3 \text{ dB}$$

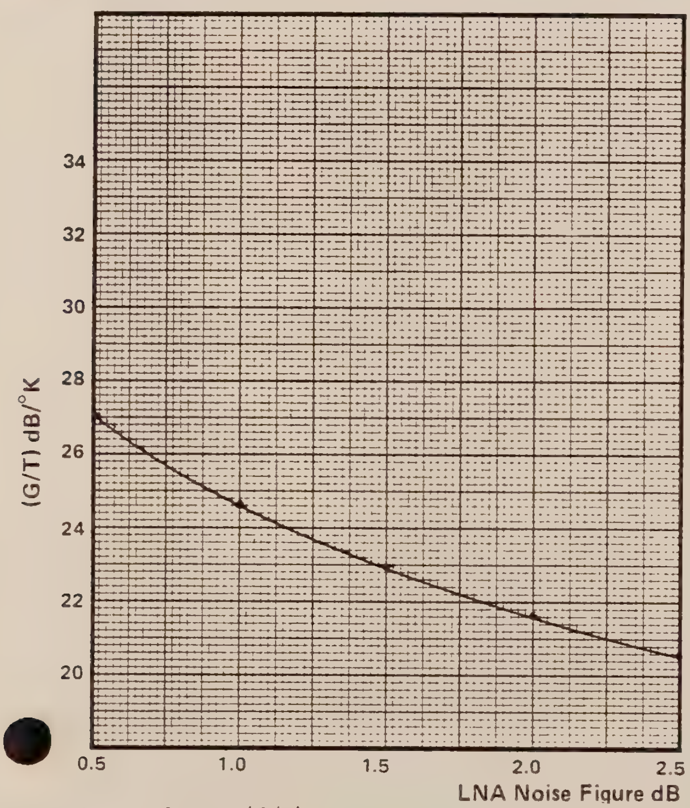
The figure of 13.2 dB often cited for 75$\mu$s pre-emphasis is for unity pre-emphasis gain at dc. It must be reduced by the 0.9 dB insertion loss necessary to put the pre-emphasis crossover at 1 kHz.



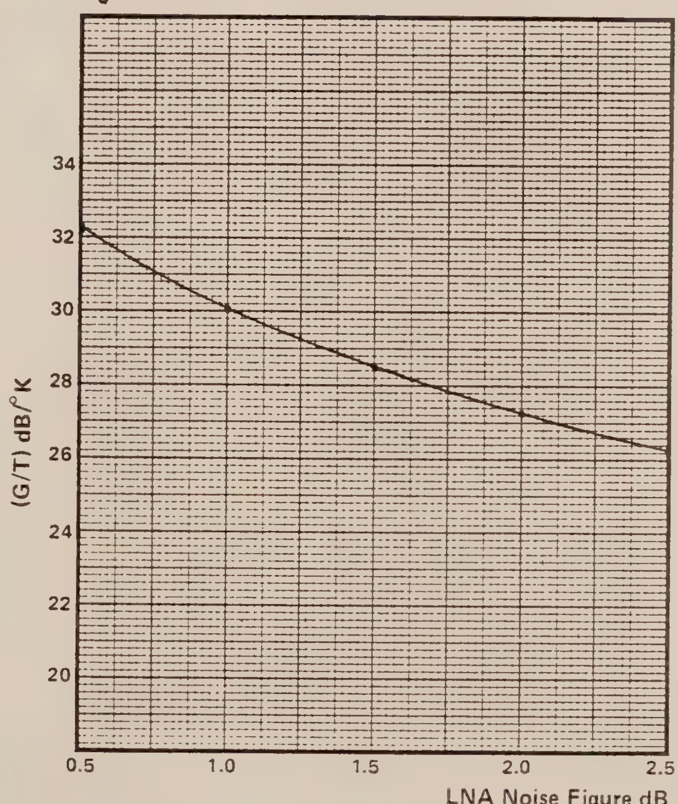

5 Meter System Temp
Figure 3A



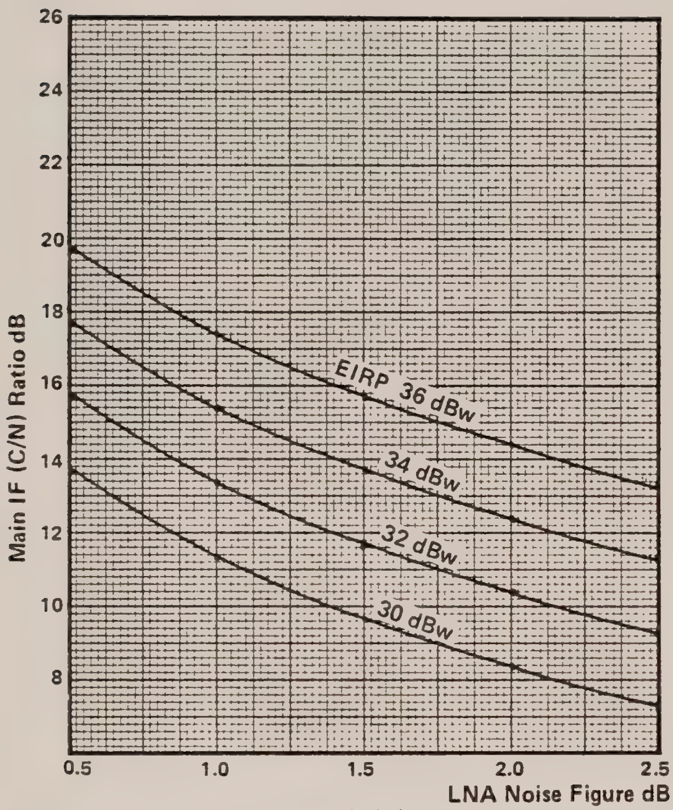

10 Meter System Temp.
Figure 3B




5 Meter System (G/T)
Figure 4A

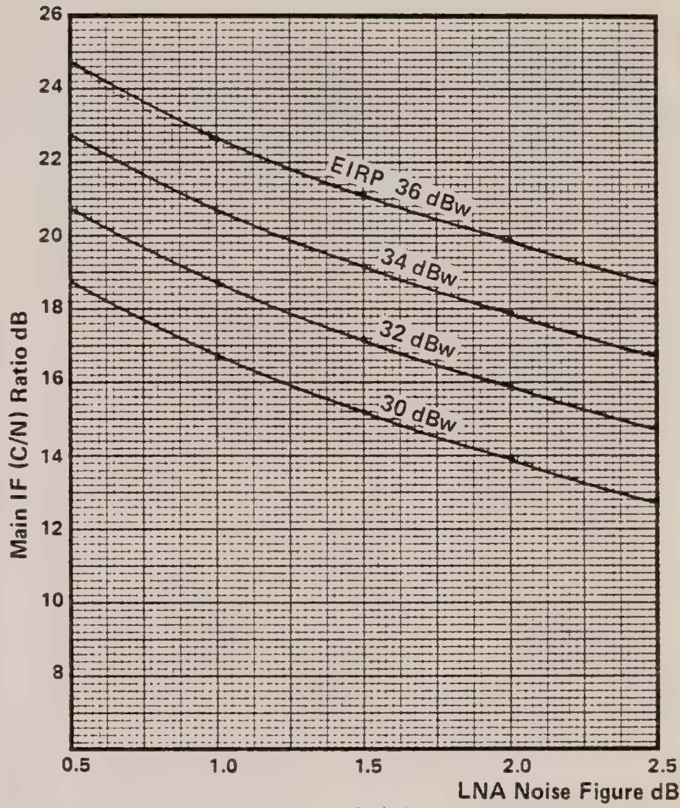



10 Meter System (G/T)
Figure 4B



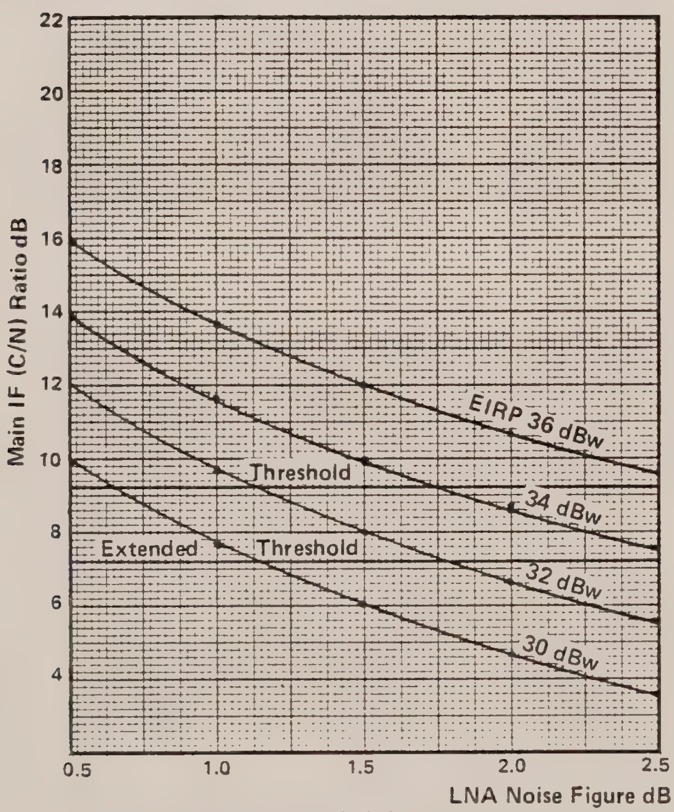

5 Meter System Clear Sky (C/N)

Figure 5A



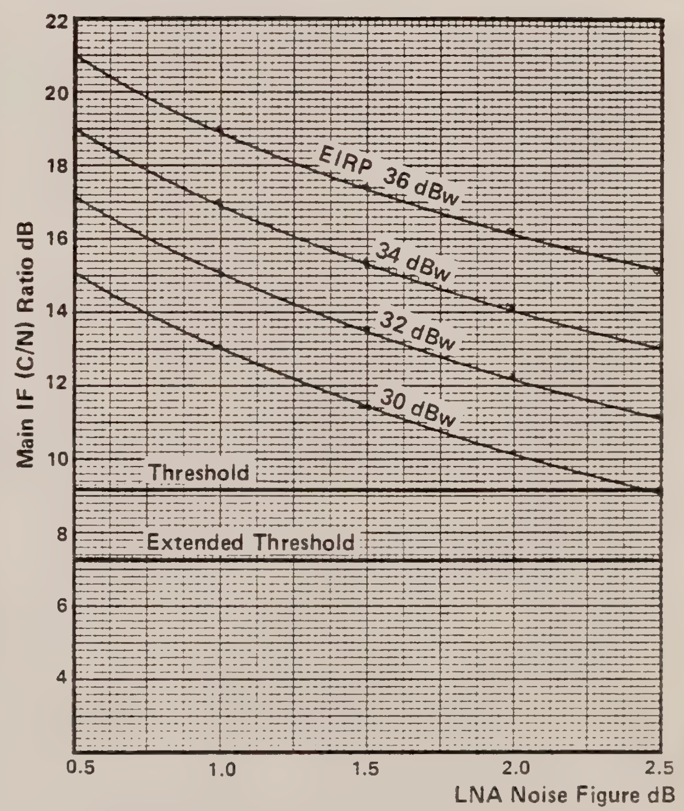

10 Meter System Clear Sky (C/N)

Figure 5B



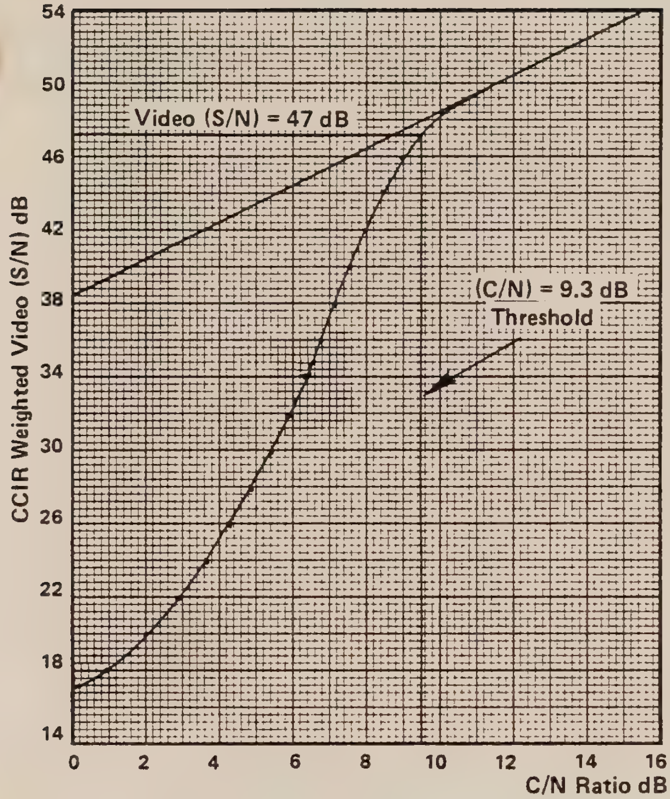

5 Meter System Degraded (C/N)

Figure 6A



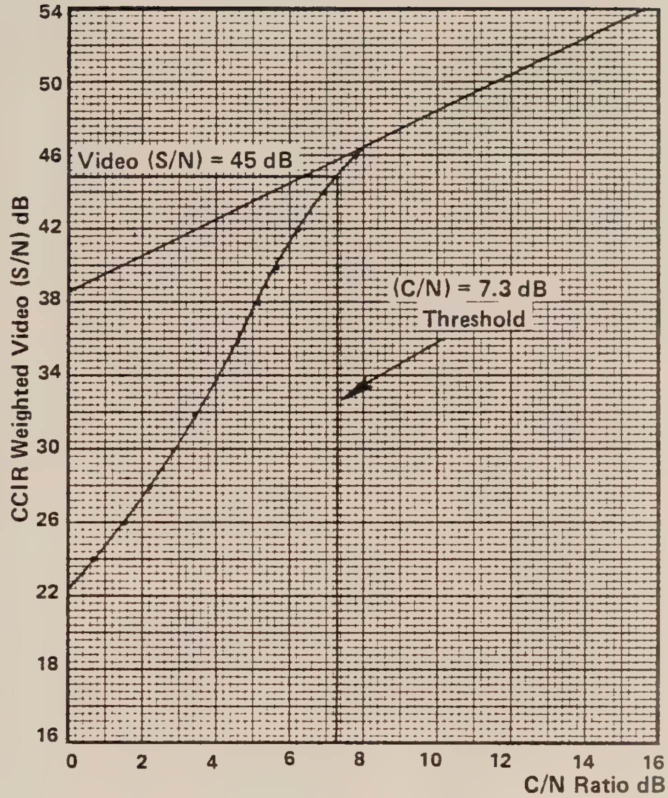

10 Meter System Degraded (C/N)

Figure 6B



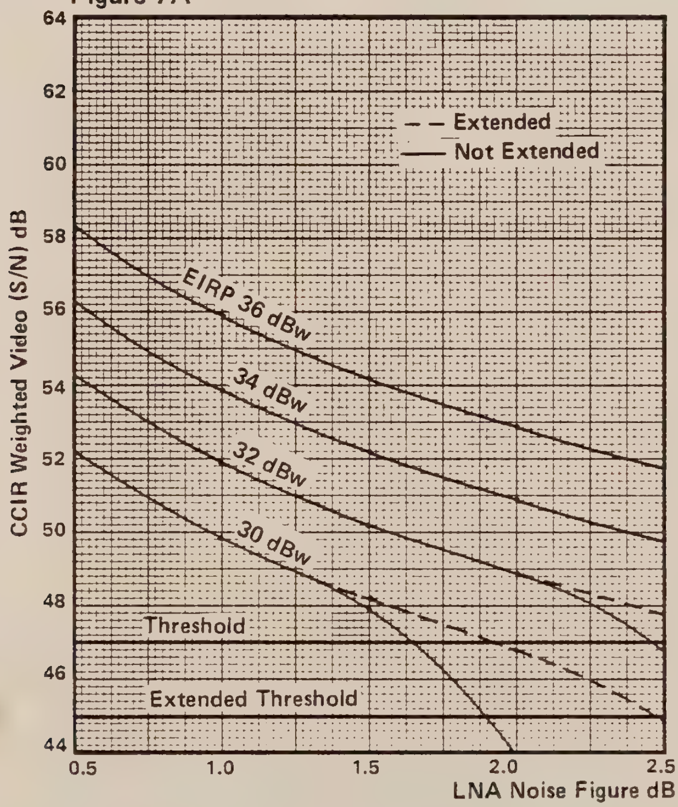

Video (S/N) vs. Main IF (C/N)
Without Threshold Extension
Scientific-Atlanta 414

Figure 7A



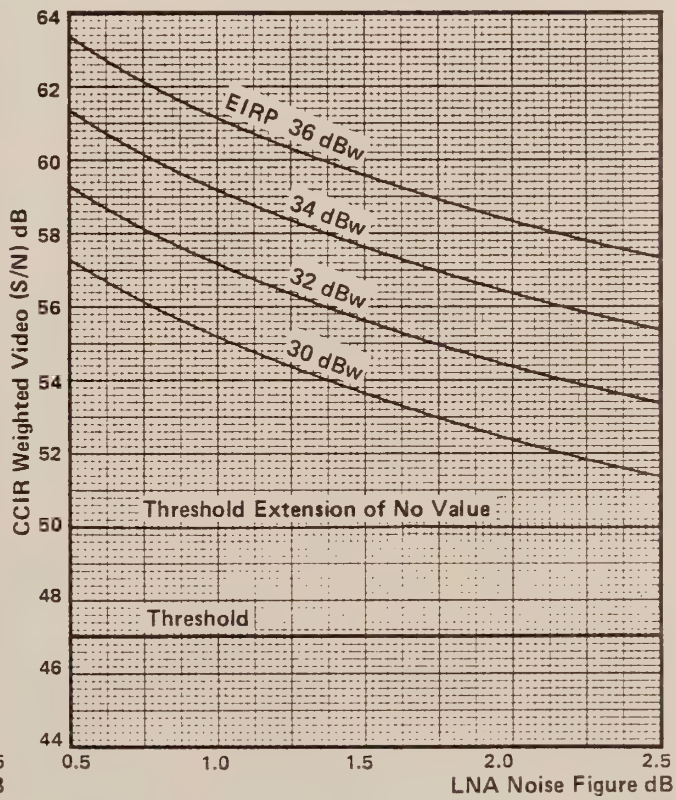

Video (S/N) vs. Main IF (C/N)
With Threshold Extension
Scientific-Atlanta 414

Figure 7B



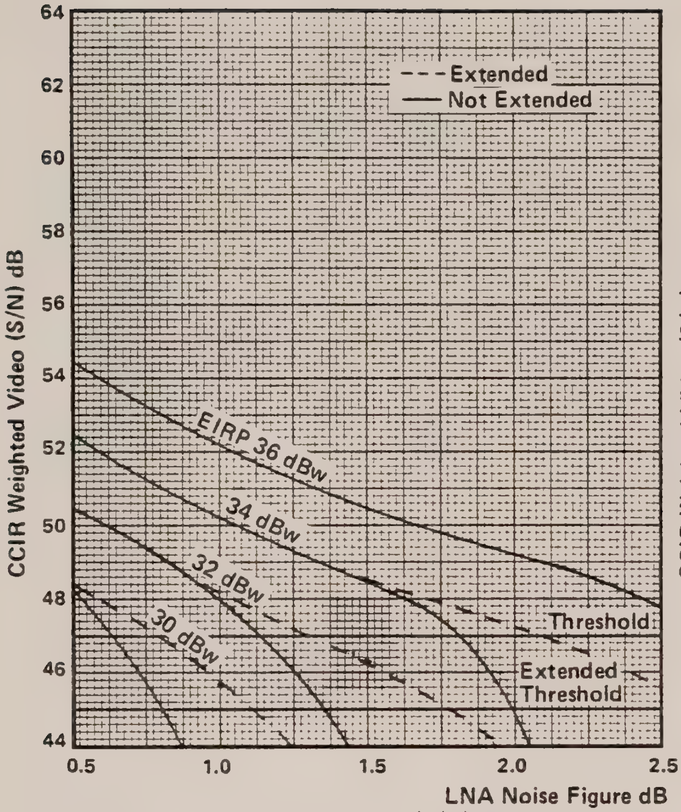

5 Meter Clear Sky Video (S/N) Ratio

Figure 8A



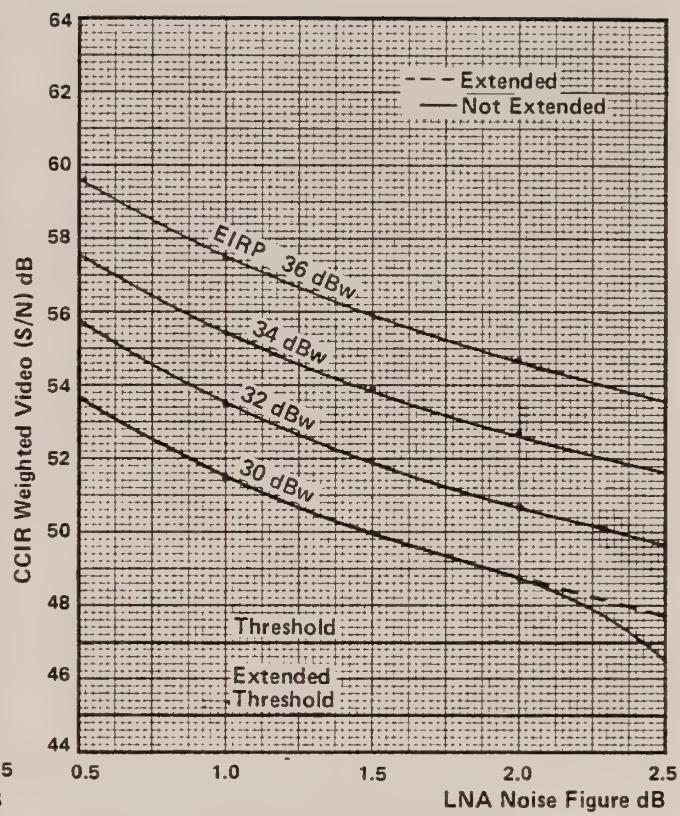

10 Meter Clear Sky Video (S/N) Ratio

Figure 8B



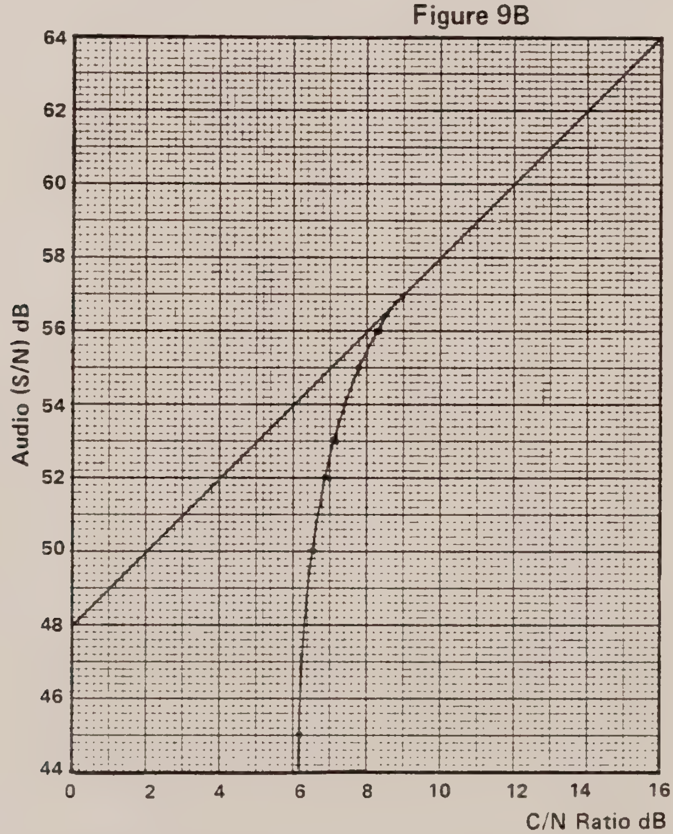

5 Meter System Degraded Video (S/N) Ratio

Figure 9A



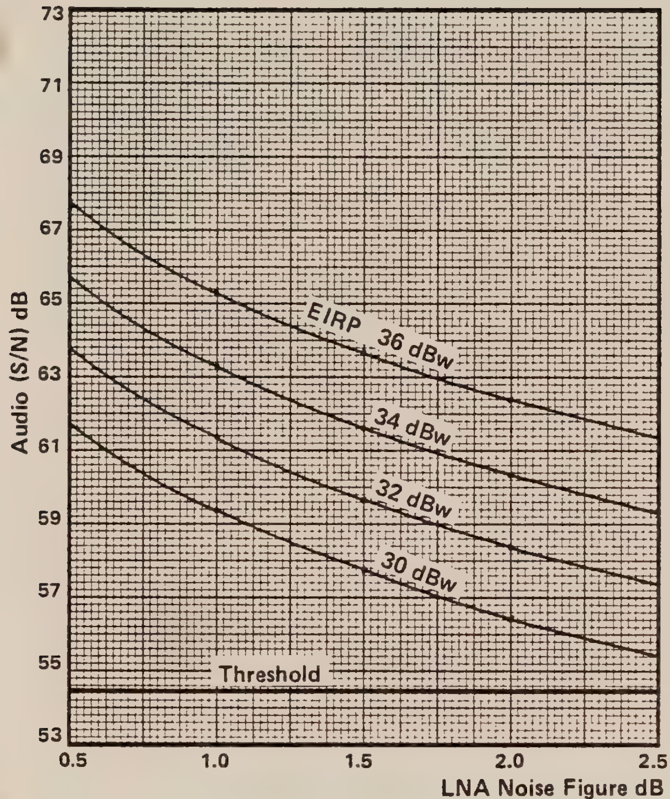

10 Meter System Degraded Video (S/N) Ratio

Figure 9B

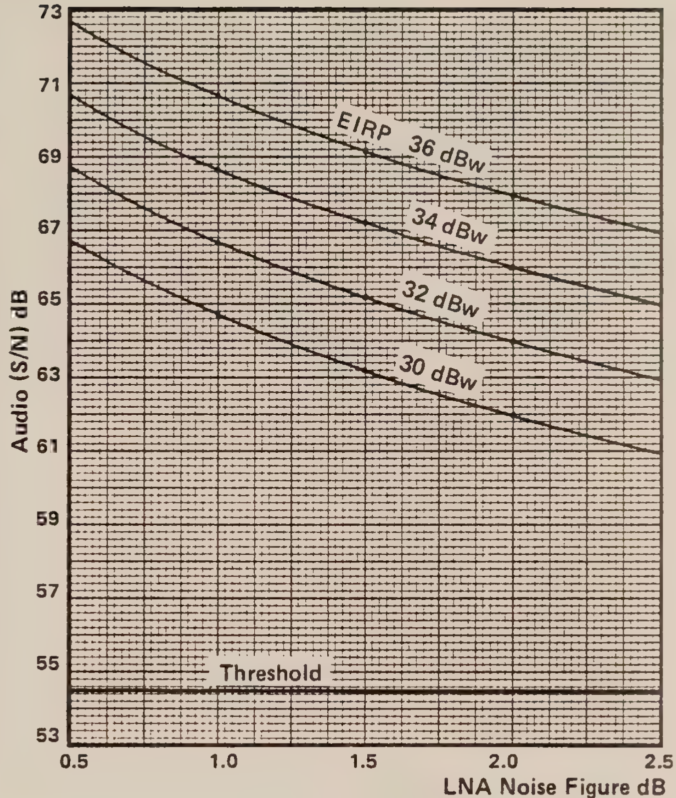



Audio (S/N) vs. Main IF (C/N)
Scientific-Atlanta 414

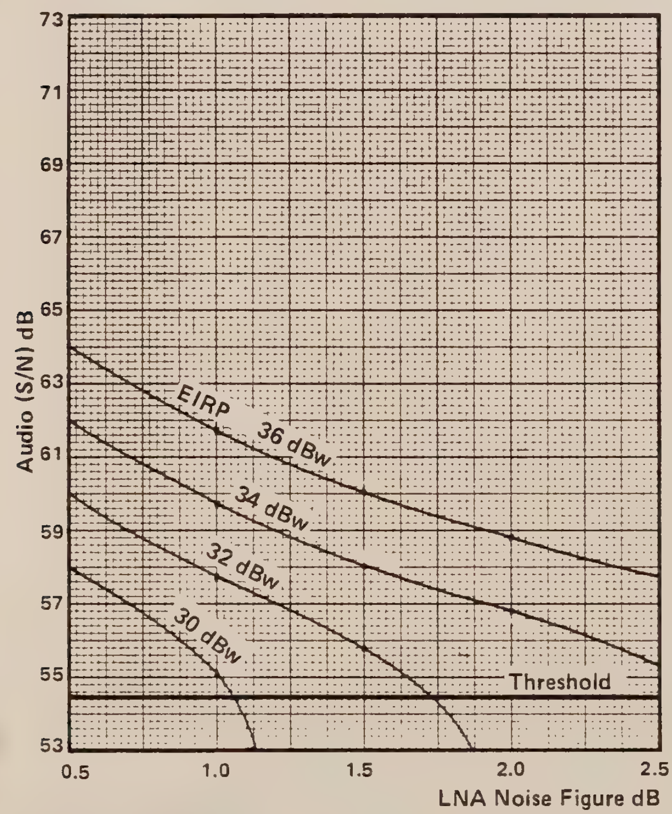
Figure 10



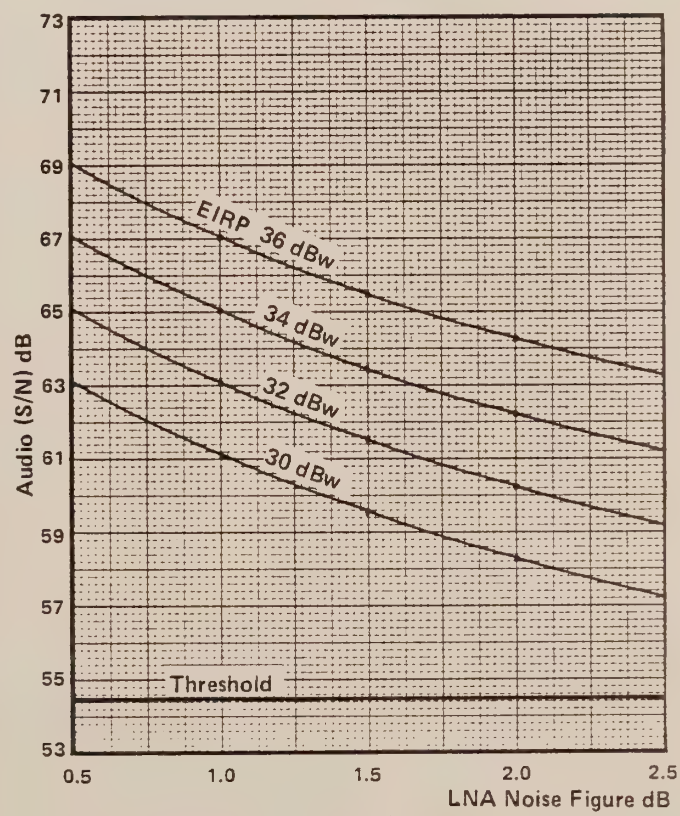

5 Meter Clear Sky Audio (S/N)
Figure 11A



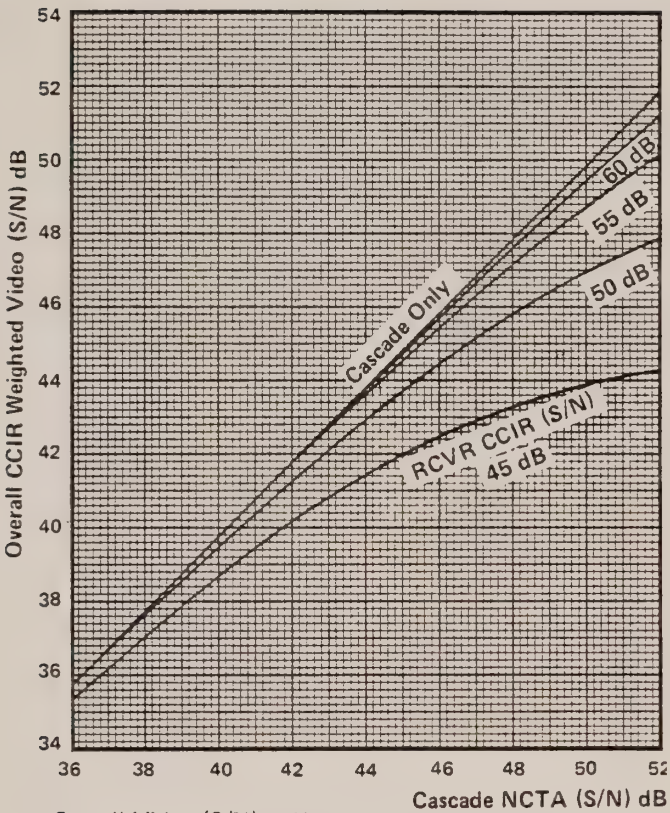

10 Meter Clear Sky Audio (S/N)
Figure 11B



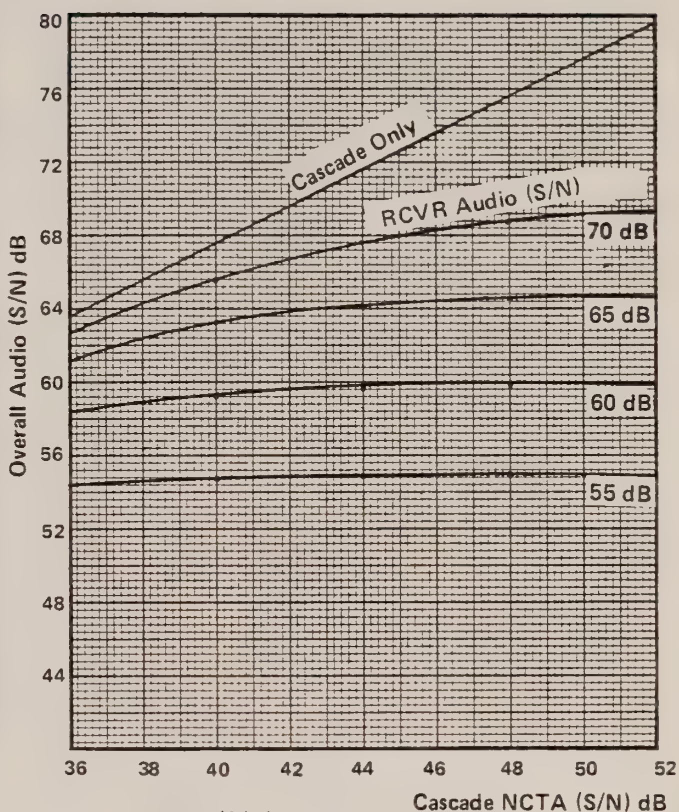

5 Meter Degraded Audio (S/N)
Figure 12A




10 Meter Degraded Audio (S/N)
Figure 12B




Overall Video (S/N) at Home
Figure 13A




Overall Audio (S/N) at Home
Figure 13B

# DESIGN AND SPECIFICATION CONSIDERATIONS OF GaAs FET LOW NOISE AMPLIFIERS

Richard D. Posner, Ph.D
Chief Engineer
Amplica, Inc.
Newbury Park, California

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## DESIGN AND SPECIFICATION CONSIDERATIONS OF GaAs FET LOW NOISE AMPLIFIERS

Within the last five years, technical advances and regulatory changes have resulted in a considerable reduction in price of the major cost components of earth terminals. This has applied commensurate pressure on the other component manufacturers to develop design approaches that will minimize price. With respect to the LNA, the coincidental introduction of the microwave Gallium Arsenide Field Effect Transistor (GaAs FET), has resulted in considerable (up to 10:1) reduction in cost as compared with parametric amplifiers. Since introduction five years ago, these amplifiers have been installed and have been working with exceptional reliability in thousands of locations. It is the purpose of this brief paper to discuss some of the salient points of interest of this key element of earth terminals. In particular, the following topics should be of general interest:

- Description of a GaAs FET
- Description of a GaAs FET LNA
- Available Options
- Typical Performance
- Reliability and Failure Modes
- Precautions
- Future Trends

### GaAs FET Description

The critical element in the LNA is the microwave GaAs FET. While microwave silicon bipolar transistors have existed for many years, their utilization results in an amplifier with, at best, a noise temperature of 330°K. The resulting net system G/T would preclude all but very limited communication applications. By contrast, the microwave GaAs FET LNA is currently providing noise temperatures as low as 100°K at very low costs when compared with parametric amplifiers.

Figure 1 shows a schematic of a GaAs FET device. Basically, it is the solid state equivalent of a triode. Current flows from drain to source through the "epitaxial layer", i.e., a very thin lightly doped region on the surface of the GaAs bulk material. The gate is insulated but provides an electric field which affects the resistivity of the epitaxial layer and thus controls current.

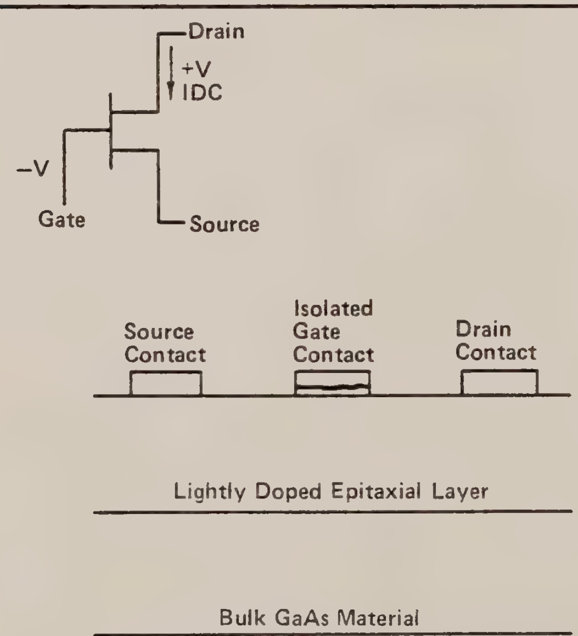



Figure 1. Basic GaAs FET Structure

Figure 2 shows a picture of an actual GaAs FET "chip". Of note are the extremely small dimensions of the metalization. In general, the smaller these dimensions, the better the RF performance.

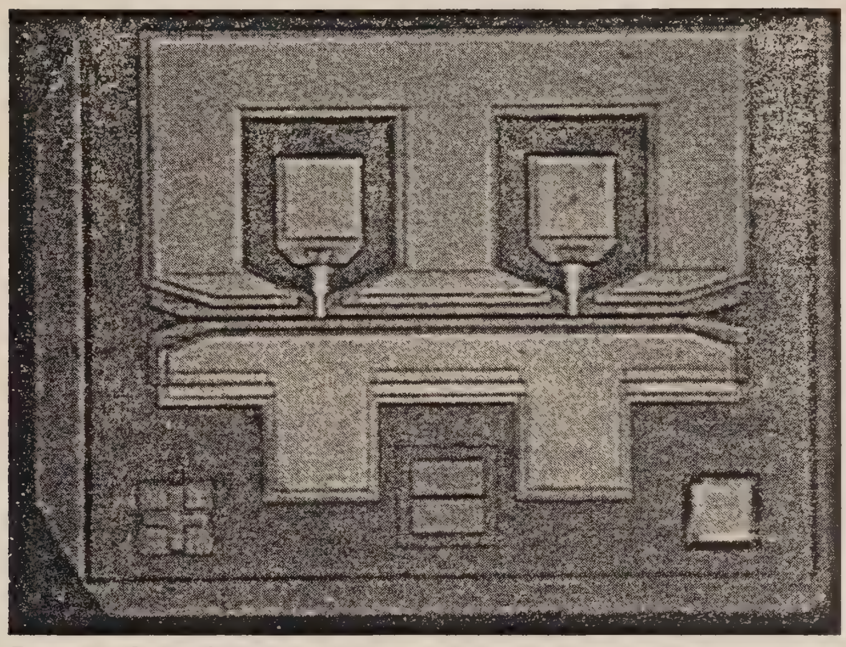


**Figure 2. GaAs FET Chip**

Figure 3 shows an actual packaged GaAs FET as it is used in the manufacture of the amplifiers. The FET package is hermetically sealed, which, in combination with the weather sealing of the overall amplifier package, provides excellent siolation of the delicate chip from the elements.

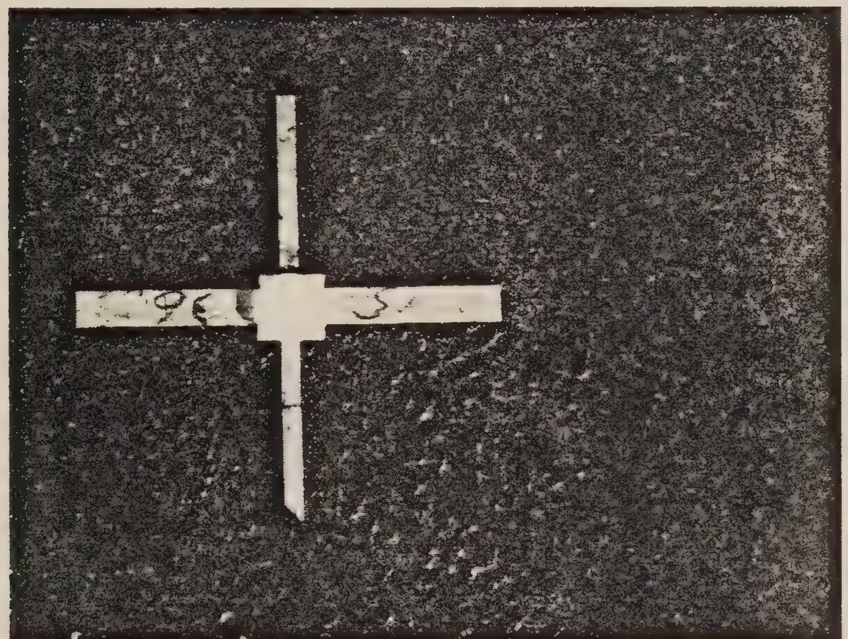


Figure 3. Packaged GaAs FET

**GaAs FET LNA Block Diagram**

Figure 4 is a picture of a typical LNA. This unit is basically a sub-system which performs a number of functions in addition to low noise amplification.

* Establish a high system overall G/T ratio with good reliability.
* Provide high, distortion free, RF gain.
* Transition from the antenna waveguide transmission mode to the TEM coaxial system mode.
* Isolate system power distribution variations and conducted interference from the RF output signal.
* Provide a RFI/EMI tight weatherproof enclosure for the actual circuitry.
* Provide adequate mechanical support so as to allow connection of a long output coaxial cable to the unit.

Possible optional requirements include:

* Fault monitoring
* Redundancy
* Multiple power source capability

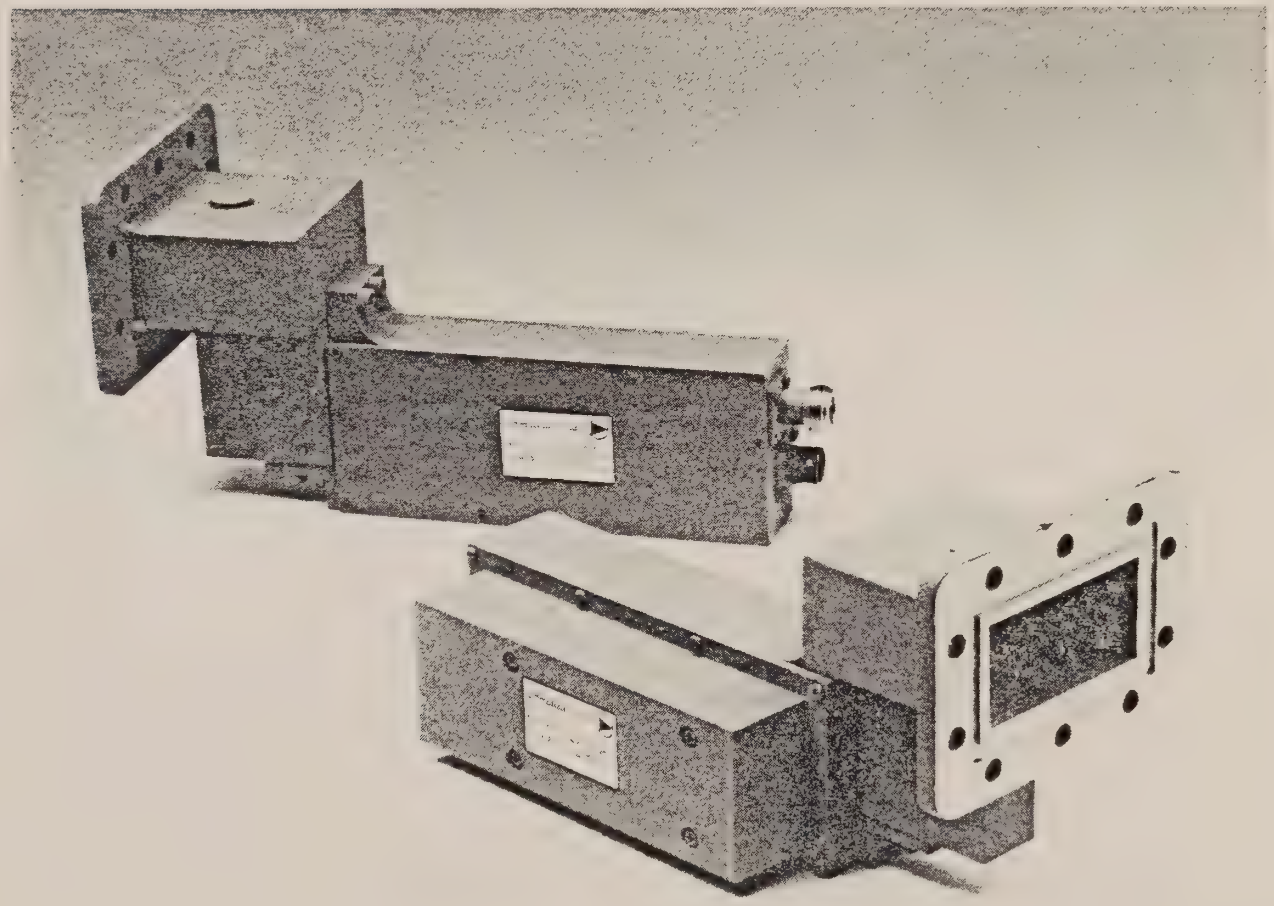


Figure 4. Typical GaAs FET LNA

Figure 5 is the electrical block diagram of a typical "Basic" LNA. As shown, directly at the input is a waveguide-to-coaxial adapter integrated with a very low loss isolator. This isolator serves a two-fold purpose: insuring that the antenna operates into a very low VSWR (1.15:1 typical) and maintaining a constant source impedance to the GaAs FET. The latter is extremely important as the low noise figure of a GaAs FET is extremely sensitive to source impedance.

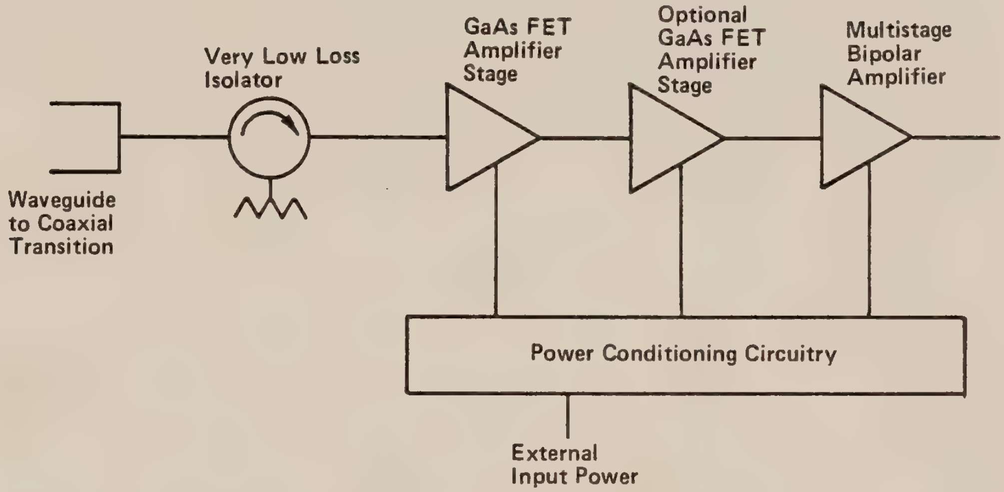



Figure 5. Block Diagram of Basic GaAs FET LNA

Either one or two GaAs FET stages are utilized, depending on required overall noise figure. This can be seen from the equation for overall noise figure ($F_O$) for a multistage amplifier

$$F_O = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} \cdots + \frac{F_N - 1}{\prod_{i=1}^{N-1} G_i}$$

Since each GaAs FET stage has approximately 12 dB gain, the use of two stages reduces the higher noise contribution of the following bipolar stages by a factor of 250, whereas a single GaAs FET reduces it by 16 (adequate for higher noise figure applications.) As many bipolar stages as possible are utilized in these LNA's because of cost considerations. A microwave bipolar transistor is typically less than one-tenth the cost of a microwave GaAs FET.

The bipolar and GaAs FET stages operate from dc voltages obtained from the power conditioning and regulation circuits within the amplifier. Power supply options are available to accommodate any conceivable combination of ac and dc unregulated voltages. Included in this circuit are transient protection devices to protect the amplifier from short duration line voltage surges.

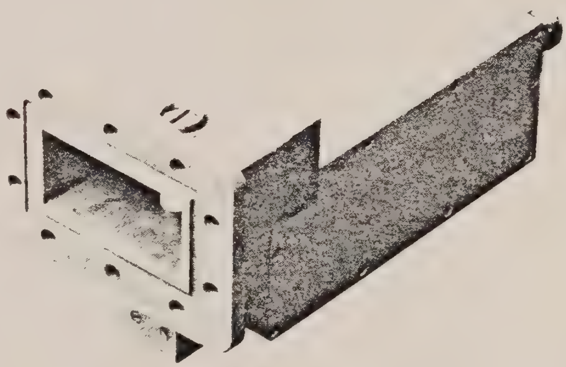
As an option, fault monitor circuitry can be provided that tests the status of each amplifier stage. An out-of-tolerance condition will cause a relay to close, which can be used to energize a standby LNA in a dual redundant system.

**Typical Performance**

Figure 6 is a data sheet for GaAs FET LNA's from Amplica, Inc. and typical of the industry. As can be seen, the specifications are given in terms convenient for the manufacturer. Traditionally, there has existed a dichotomy between the ultimate user, the system engineer, and the component manufacturer as to just how to specify and test a component. The problem is one of different means to the same end: all want the ultimate user to achieve his objective. The LNA manufacturer must specify and test his product so that when inserted in a downlink receiver, good performance will result, i.e., a clear, noise-free TV picture. Thus, it is useful to discuss not only typical results that GaAs FET LNA's achieve, but their relation to ultimate signal reception.

# 3.7 to 4.2 GHz Low Noise Amplifiers 95° K to 290° K Noise Temperature

AMPLICA presents a new family of SC Band Low Noise GaAs FET Amplifiers designed with performance, production and economy in mind. Model 729CWNL is currently in production offering 120° K noise temperatures over the full 3.7 - 4.2 GHz frequency range. Other units in this family provide noise temperatures ranging to 290° K which permit effectively selecting the best Noise Temperature for your system at the lowest possible cost. Model 729 thru 733CWNL all possess rugged weatherproofed construction with waveguide pressurization capability. Standard units come with regulated power supply allowing the DC Voltage to vary from +15 to +25 volts without degrading performance. Options for negative power supplies and AC supplies are available. Just recently joining the family of Low Noise Amplifiers for satellite earth station requirements is the Ultra Low Noise Model 728CWNL which offers a noise temperature of 95° K.



## The following are the SC Band Low Noise GaAs FET Amplifier Common Specifications

| | |
|---|---|
| Frequency Range: | 3.7 to 4.2 GHz minimum |
| Gain: | 50 dB minimum |
| Gain Flatness: | ± 0.5 dB/500 MHz<br>± 0.25 dB/40 MHz |
| Output Power @ 1 dB Gain Compression: | +10 dBm minimum |
| Intercept Point: | +20 dBm minimum |
| Input VSWR: | 1.3 maximum |
| Output VSWR: | 1.5 maximum |
| Input Power/Current: | +15 to +25 Vdc @ 110 mA nominal |
| Input Connection: | CPR 229G |
| Output Connection: | Type "N" Female |
| Weatherproofing: | Provided |
| Mating AC or DC Connector: | Supplied |
| Size: | See attached outline drawing |

| Model No. | Noise @ +23 C |
|---|---|
| 728CWNL | 95° K (1.23 dB) |
| 729CWNL | 120° K (1.5 dB) |
| 730CWNL | 150° K (1.8 dB) |
| 731CWNL | 180° K (2.1 dB) |
| 732CWNL | 225° K (2.5 dB) |
| 733CWNL | 289° K (3.0 dB) |

NOTE: For −18 to −30 Vdc add (−1) to model number.
For −40 to −60 Vdc add (−2) to model number.
For 115 Vac add (−3) to model number.

Figure 6. Typical Data Sheet

NOISE FIGURE: The noise figure (in dB) is given by: $NF = 10 \log_{10} (1 + T_e / T_o)$ where $T_e$ is the effective noise temperature (in °K) that the LNA adds to the system (i.e., in addition to the antenna noise) and $T_o$ is 290°K.

Figure 7 is a series of graphs of equivalent noise temperature versus frequency for typical amplifiers with guaranteed noise figures of 1.25, 1.5, and 1.8 dB. Note that noise temperature can be improved over narrow bandwidths.

GAIN: Typical LNA's have 50-55 dB nominal gain.

GAIN VARIATION OVER FREQUENCY: The maximum gain variation (in ± dB's) allowable over a given frequency range (usually the entire 3.7 - 4.2 GHz range). Of most importance is the variation over the channel bandwidth, as this can cause differential gain and phase, which can ultimately lead to color distortion in a TV picture or intermodulation distortion on a multiplexed telephone signal.

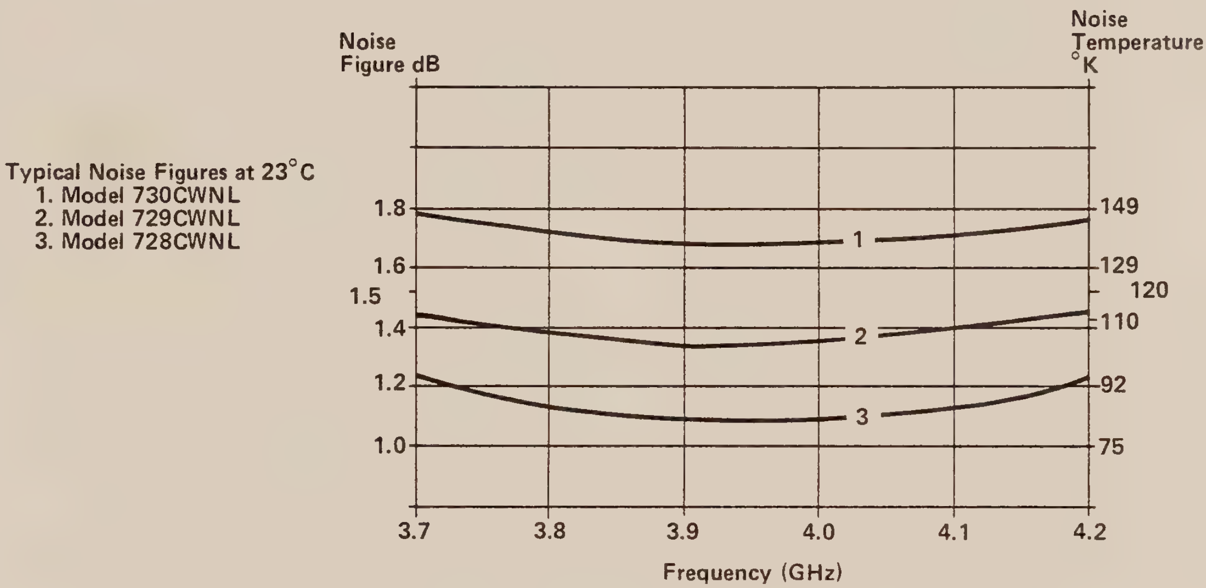



Figure 7.

Figure 8 shows a typical plot of the gain variation from nominal versus frequency. Most amplifiers, specified at ±.5 dB gain variation, achieve ±.25 dB gain variation over the entire 3.7 - 4.2 GHz band and ±.05 dB over any 40 MHz segment.

GROUP DELAY DISTORTION: This parameter (expressed as linear nsec/MHz, parabolic nsec/MHz$^2$, and peak-to-peak nanoseconds) directly causes differential phase and gain distortion resulting in cross-modulation and intermodulation on multiplexed telephone signals.

INTERCEPT POINT: The Intercept Point (ICP) is a parameter used to facilitate calculation of the intermodulation (IM) products of multiple carriers (i.e., this does not pertain to baseband distortion other than the effective noise loading from the IM product of another carrier.) Figure 9 shows the relationship of ICP to the various IM products. Typical ICP for earth station LNA's are +22 dBm.

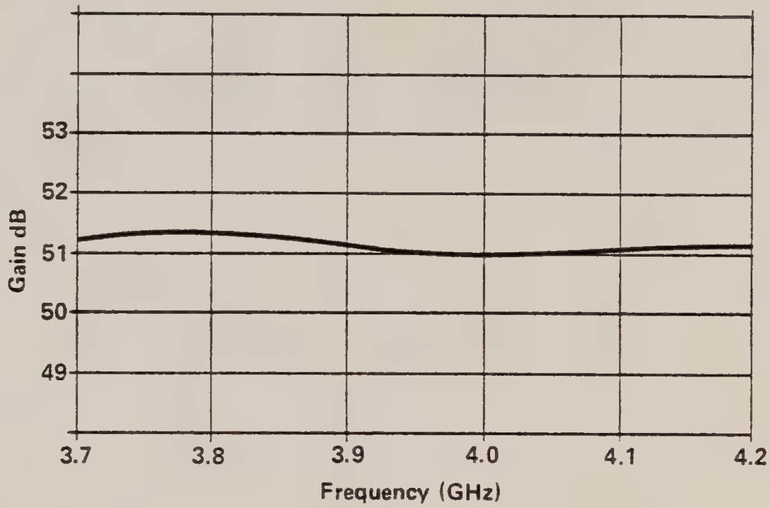
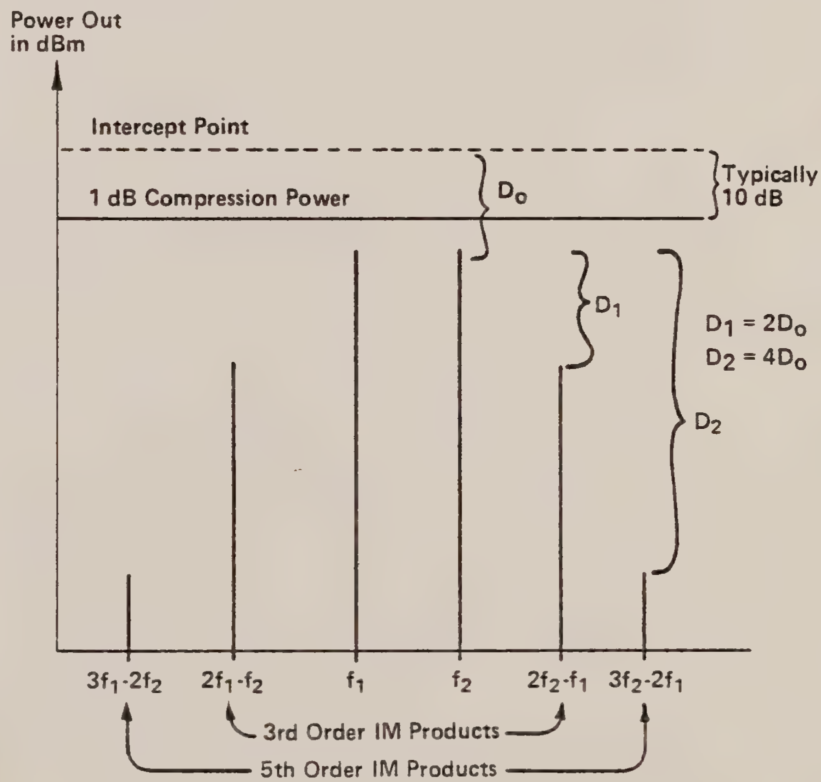



Figure 8. Typical Gain Variation at 23°C Ambient




$D_o$ is difference (in dB) Between the Power of Each of 2 Equal Output Signals and the ICP.

$D_1$ is the Relative Level of the 3rd Order IM Products.

$D_2$ is the Relative Level of the 5th Order IM Products.

Figure 9. Amplifier Linearity and IM Performance

1 dB COMPRESSION POINT: This is the output power level at which the small signal gain of the amplifier is reduced by 1 dB. In general, this represents the maximum useful output power level of the LNA because beyond this point non-linearities can cause additional signal distortion. As shown in Figure 6, the ICP is typically about 10 dB higher than the 1 dB compression point. A typical compression point is + 12 dBm.

VSWR: The Voltage Standing Wave Ratio is microwave terminology expressing degree of impedance match. The lower the VSWR, the better the match. Low input VSWR is critical because mismatch can result in lost signal and thus increases effective noise temperature. For an input VSWR, S, the effective additional noise temperature, $\triangle T$, of the antenna or amplifier is given by:

$$\triangle T = \frac{(S-1)^2}{4S} \; 290$$

where SF is the noise figure of the amplifier.

Normally, antennas and LNA's are tested with the mismatch effects included. Most LNA's have input VSWR's less than 1.15:1 and output VSWR's less than 1.3:1.

GAIN VARIATION WITH TEMPERATURE: Obtaining gain from GaAs FET or Bipolar microwave transistors involves utilizing a number of its parameters (e.g., input and output impedance and high frequency current gain, etc.) Since each of these parameters is subject to change over temperature, there is a net change in gain over the environment of a typical earth station. This can be as high as 5 dB over a $-40$ to $+50°$C temperature range. Special compensation techniques can reduce this to $\pm.5$ dB over 0–40°C as shown in Figure 10. However, with the excellent automatic gain control circuits found in all modern receivers, gain compensation is usually not necessary.

Gain Variation with Ambient Temperature

| | |
|---|---|
| 50°C | 122°F |
| 23°C | 73°F |
| 0°C | 32°F |

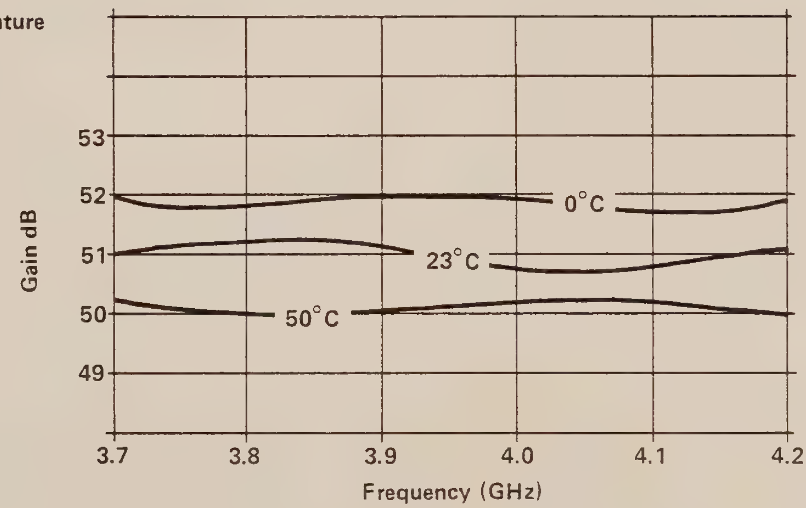



Figure 10.

**Noise Temperature Variation with Temperature** The ambient temperature of the LNA has a very strong effect on equivalent noise temperature. Figure 11 shows the noise temperature versus frequency curves with ambient temperature as a parameter. Obviously, system designers must consider the worst case ambient temperature in specifying an LNA type, as there is no way to compensate for this effect.

**Reliability and Precautions** As discussed previously, a GaAs FET LNA is constructed using transistors, GaAs FET's, and passive electronic components. With no electromechanical components, the unit is a basically reliable assembly from the point of view of wearing out. A reliability analysis performed according to the Air Force handbook: MIL-HDBK-217B, results in a calculated MTBF in excess of 130,000 hours (15 years.) However, reliability involves not only random failures but susceptibility to external failure causes. In this respect, the LNA must be treated as the delicate assembly it is. The circuitry consists of small components and transistors with, as previously shown, extremely fine geometry. Operating at 4000 MHz, this circuitry is easily perturbed. Such external phenomena as power line transients, mechanical over stress, or excessive RF power from lightning, can cause damage.

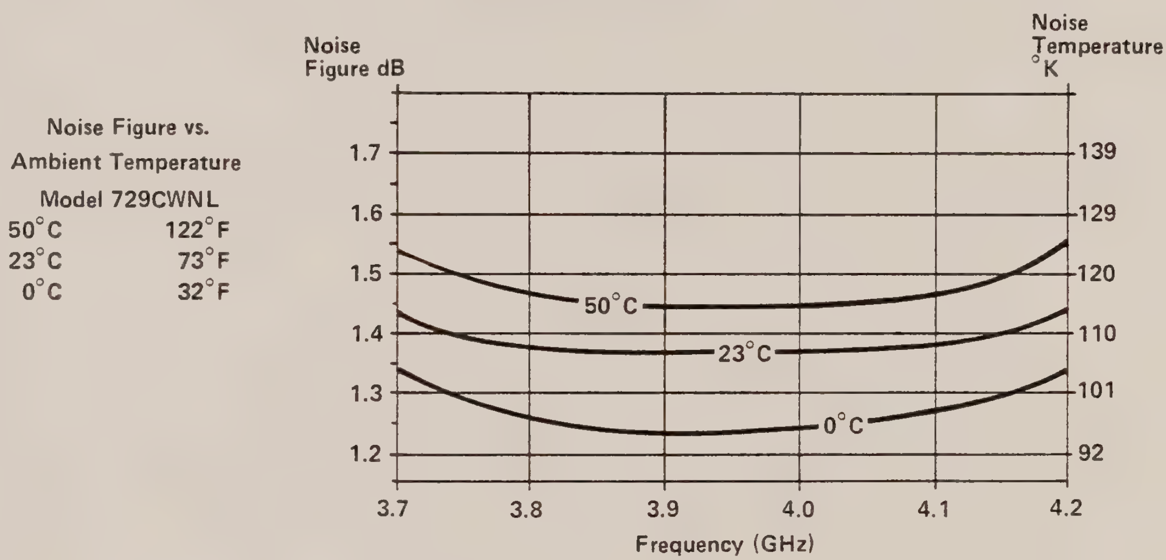



Figure 11.

In particular, Amplica has analyzed the cause of failure of returned amplifiers. Figure 12 shows the distribution of these returns. As shown, only 12% of the returns result from random failures or workmanship.

Approximately 50% of the returns have a failure of the input GaAs FET. This is due to RF and/or line transients which, in most cases, are lightning induced. The latest studies measuring the properties of lightning induced power line transients indicate that a single lightning discharge results in typically, a series of 20 pulses of approximately 20 microseconds duration per pulse. The field results show peak induced currants up to 15,000 ampheres typically and on direct line strikes, up to 60,000 ampheres. A number of protective devices are included in the LNA but, more adequate protections require special energy clipping subsystems to be attached to the line. Even in this case, a direct lightning strike cannot be sustained without damage.

An additional 30% of returns are due to physical mishandling with the bulk of failures resulting from excess force being exerted on the units. Apparently, the LNA shape offers either an attractive footstep or a convenient handle by which to steer the antenna.

The next most prevalent cause for LNA failure is moisture at 8%. Of particular concern are installations which locate the LNA at the focal point of the antenna with no waveguide pressurization. The combination of extreme temperature cycling, direct sunlight, and direct precipitation eventually allows moisture to penetrate the waveguide, and soon deteriorates the electrical performance.

In terms of user precautions to minimize the chance for unit failure, the most important step would be the installation of line transient suppression and adequate grounding. As noted, this could protect against all but a direct lightning strike. Finally, it is recommended that as much physical protection as possible, both from the elements and from physical abuse, be provided.

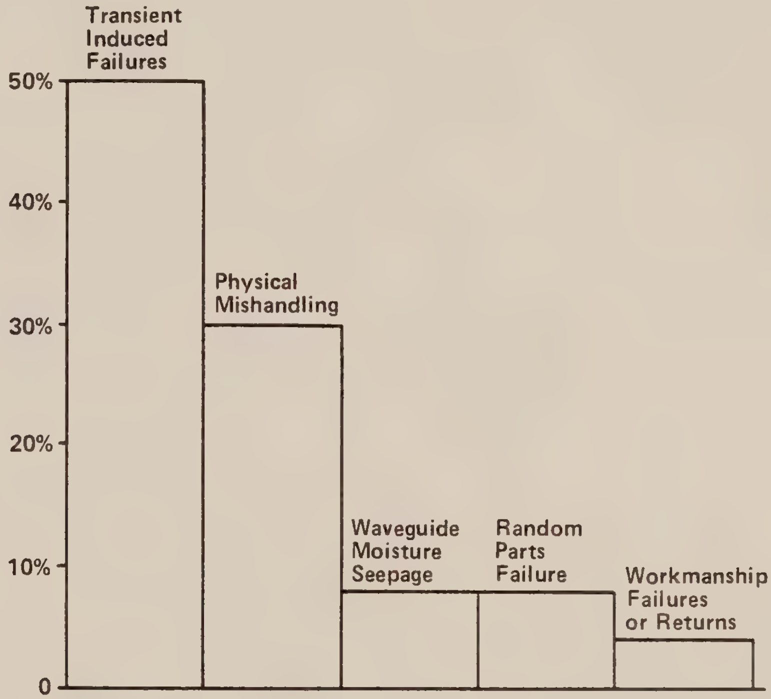



Figure 12. Distribution of Causes of Returned Amplifiers

**Future Trends** Over the last six years dramatic improvements in reliability and performance of GaAs FET LNA's have been achieved. During this period, thousands of amplifiers have been delivered at a continually decreasing cost. The most important component in the GaAs FET LNA is the actual GaAs FET device, and this technology is in an extremely dynamic phase with more companies producing high quality GaAs FET's, and with the state-of-the-art continually improving. Thus, this trend of product improvement can be expected to continue for the next few years. Figure 13 shows the important parameter of equivalent noise temperature versus time, both past and projected future.

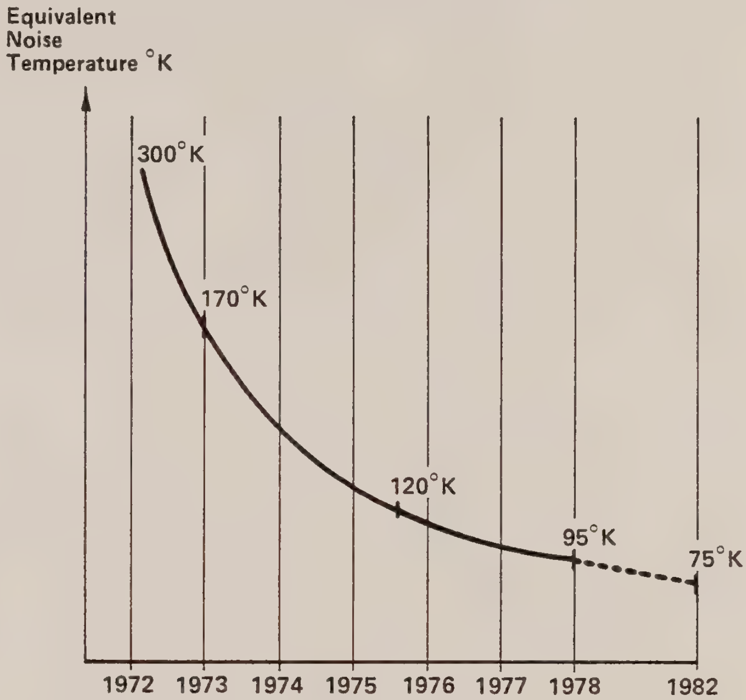



Figure 13. LNA Equivalent Noise Temperature versus Time

**Summary** This brief overview of GaAs FET LNA's for earth terminal applications has, hopefully, indicated that these microwave components represent a very reliable and cost-effective way to implement the low cost ground station. Within the next couple of years, these low cost amplifiers can be expected to allow excellent system G/T ratios in all but the most remote high density application.

# VIDEO RECEIVER PERFORMANCE
# AND
# DESIGN CONSIDERATIONS

Written By:
Heinz Wegener
Edited By:
Edward J. Chapman
Manager, GCE Engineering
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## Introduction

*The part of the video receive earth station that directly affects all portions of video and audio performance is the video receiver. For this reason, it is very important that both specifications and basic design differences are understood. Following is a brief summary of the purpose of the video receiver, definitions of various specifications and how they affect video performance, design tradeoffs, and a discussion of Scientific-Atlanta's 411 and 414 Receivers.*

## The Purpose of the Video Receiver

*The first function of the video receiver is to select the carrier to be demodulated and reject unwanted carriers. Selection of the carrier is achieved by translating the RF frequency to a lower intermediate frequency (IF). Conversion to a lower frequency does not alter the characteristics of the carrier and its associated modulation and allows more economical processing of the carrier. In addition gain devices, filters, delay equalizers, limiters, and discriminators are technically easier to implement and test at lower frequencies.*

*The receiver also provides automatic gain control (AGC) of the incoming signal. AGC is required to provide a constant level into the demodulator and compensates for level variations due to changes in uplink power, transponder gain changes, changes in transmission parameters (weather, elevation angle), gain tolerance variations in system components (pre-amp,RF cable length), and variations of gain with time. Since the satellite is in a synchronous orbit with the earth and since downlink power is very closely controlled, (the transponder is usually saturated) once a system is installed an AGC range of 10 dB would probably be more than sufficient to handle any system gain variations. However, most receivers specify an AGC range (sometimes called dynamic range) of 40 to 50 dB.*

*The receiver also provides frequency discrimination of the FM signal. This function of the receiver can contribute the greatest amount of distortion of the video signal if not properly designed and implemented.*

*Once the signal is demodulated it must have several operations performed on it before it is a useable signal suitable for distribution. The basic signal processing operations are:*

*De-emphasis*
*Removal of the subcarrier from the video signal*
*Energy dispersal removal from the video signal*
*Restoration of DC level to the video signal*
*Selection and demodulation of the audio subcarrier*
*De-emphasis and filtering of the demodulated audio signal*

*In FM systems triangulation of the noise spectrum occurs during the demodulation process. This causes the noise spectrum to increase in level with an increase in modulating frequency. This results in a decreasing signal-to-noise ratio at increasing baseband frequency. To overcome this effect, a de-emphasizing network is utilized in the receiver and a matching pre-emphasing network in the transmitter. (See Figure 1). Pre-emphasis shapes the frequency response of the video signal and causes the highest frequency component of the video signal to be 13.2 dB (voltage ratio of 4.6) higher than the lowest frequency component. Figure 2 shows a pre-emphasized multiburst. The weighted S/N improvement of a pre-emphasized video signal over a flat video signal is approximately 2.5 dB for 525 line transmission. Another factor of pre-emphasis used in video transmission is the improvement in color information by the reduction in distortion of the chrominance signal by the luminance signal. By reducing the relative level of the luminance signal to the chrominance signal the amount of chrominance-to-luminance distortion caused by non-linearities in the system is reduced.*

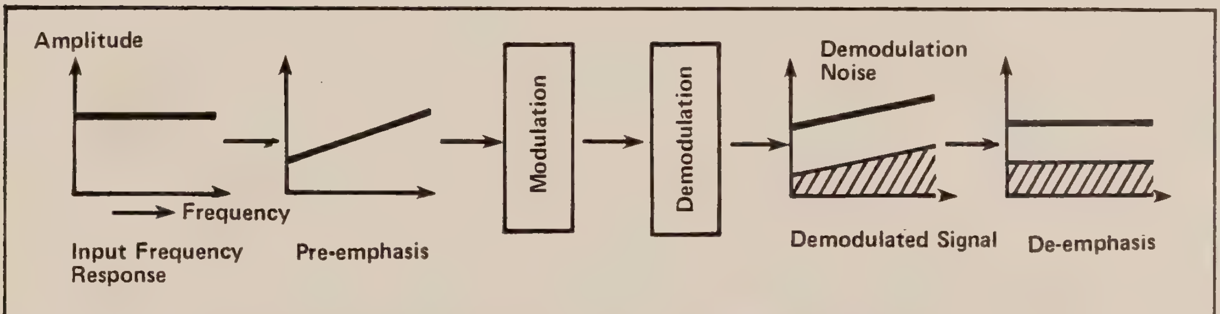
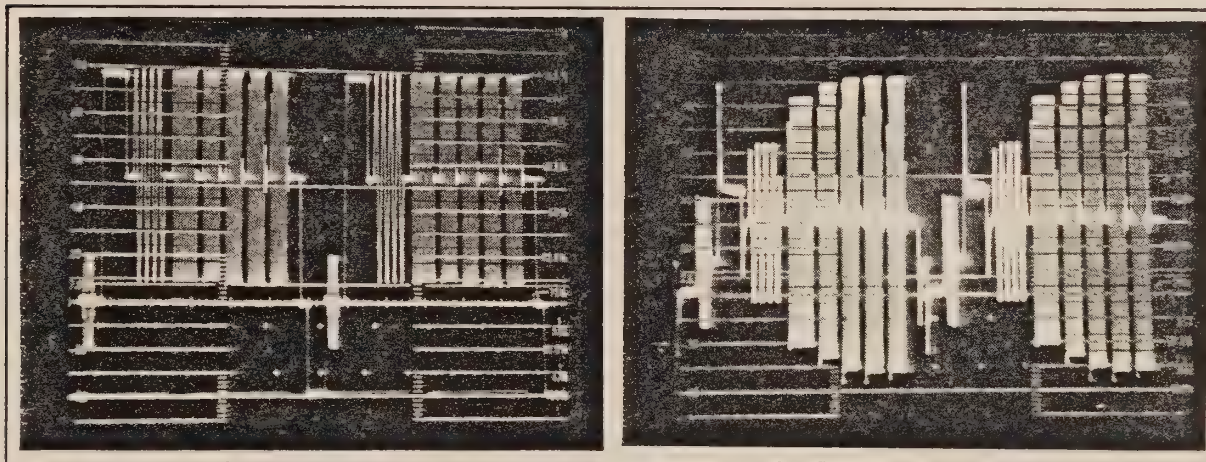



Figure 1. Pre and De-emphasis Effect On Triangular Demodulation Noise



a. Normal Multiburst

b. Pre-emphasized Multiburst

Figure 2. A pre-emphasized multiburst signal

*Removal of the subcarrier from the video is required to eliminate the possibility of subcarrier to chrominance intermodulation which could produce spurious products that fall within the video passband. Although the frequency of the subcarrier is high enough that it would probably not cause degradation of the picture it is best to remove the subcarrier as quickly as possible after demodulation to avoid potential intermodulation problems.*

*All video signals transmitted through a satellite are required to have an energy dispersal waveform. This waveform is simply a triangular waveform (whose inflection points are synchronized with the vertical blanking interval) summed in with the video signal prior to modulation. Figure 3 shows two fields of video with the dispersal waveform. The energy dispersal waveform causes the carrier to be modulated typically 1.0 MHz peak-to-peak with video and 2.0 MHz peak-to-peak when video is removed. The deviation caused by the dispersal waveform insures that the radiated power from the satellite at any one RF frequency is less than a certain maximum allowable level to minimize the probability of interference with terrestrial microwave systems and in some cases adjacent satellites, and to reduce intermodulation in half transponder video transmission. After the video signal is demodulated the triangular waveform must be removed and this is commonly done by clamping the video signal to the sync tips. In addition to removing the triangular waveform, clamping also provides dc restoration of the video signal.*

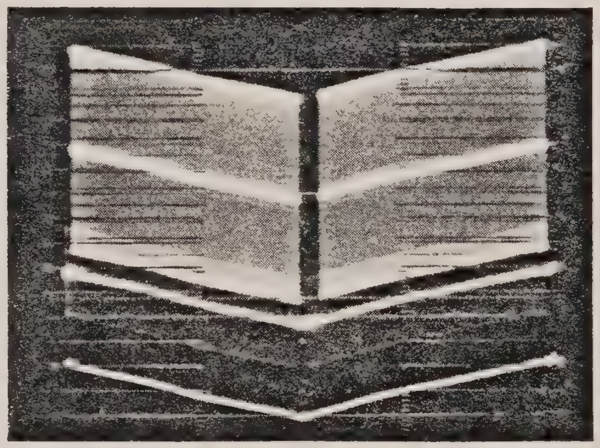


**Figure 3. Video signal with the energy dispersal waveform**

*The video associated audio is transmitted on a subcarrier which is summed in with the video signal. The subcarrier must be filtered from the video signal and demodulated to produce the audio signal. Since this is also FM modulation, the audio signal must be de-emphasized to correct for pre-emphasis (pre-emphasized modulation provides an unweighted S/N improvement of approximately 12 dB over flat modulation for the 75 µsec pre-emphasis network and 15 kHz audio format used in U.S. domestic video transmission). The audio signal is then filtered to remove unwanted frequencies and is then ready for distribution.*

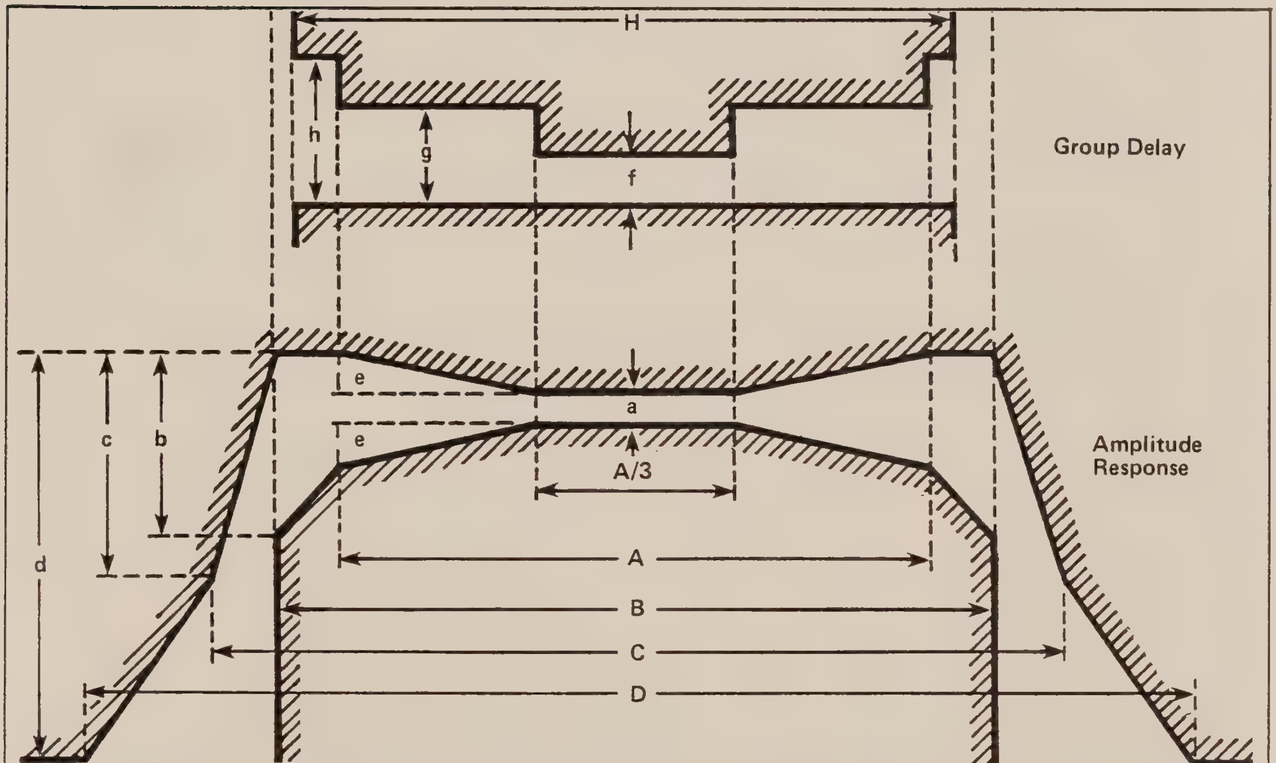
**Receiver Specifications and Performance Criteria**

*When evaluating video receivers, it is important to understand the meaning and importance of various specifications and how they relate to performance degradations. The following is a discussion of various specifications that are very important (primary), specifications that are less important (secondary) and specifications that can yield misleading information if not defined properly.*

## PRIMARY SPECIFICATIONS

**RF and IF Gain Flatness**

*Although this is an FM system and in most conventional receivers there is some form of amplitude limiting, severe amplitude non-flatness can cause AM to FM conversions to occur in the limiters which leads to intermodulation of the video signal. Intelsat document BG 28-72E gives frequency response tolerances which should be met in video receivers to minimize distortions due to gain flatness at RF and IF. Figure 4 is a reproduction of the 36 MHz mask. All Scientific-Atlanta receivers meet this mask requirement.*




| | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131630 | 36.0 | 28.8 | 36.0 | 45.25 | 60.0 | 0.6 | 2.5 | 10.0 | 25 | 0.3 | 33.1 | 3 | 5 | 15 |

Figure 4. Receiver Amplitude Delay Characteristics

**Phase Linearity - RF and IF**

*Phase linearity is commonly discussed in terms of group delay which is defined as the derivative of the phase/frequency response. The group delay limits of the video receiver should meet the requirements of the mask of Figure 4. Non-linear phase results from conventional filtering and must be equalized to provide a group delay characteristic which falls within the mask of Figure 4 to yield satisfactory performance. Group delay distortions cause the following degradations of the demodulated signal.*

1. *Baseband gain/frequency variations.*
2. *Harmonic distortion which produces luminance/chrominance crosstalk.*
3. *Baseband intermodulation which causes unwanted frequency products to occur in the video signal.*
4. *Differential phase distortions.*

**Demodulator Linearity**

*Demodulator linearity is a measure of the accuracy of the transfer function of the demodulator (volts/MHz of deviation) over its deviation range. For good performance this accuracy (linearity) should be within 1% on any portion of the deviation range. Demodulator nonlinearity causes harmonic distortion and excessive differential gain of the demodulated signal.*

**RF Return Loss**

*Because the receiver usually interfaces with the pre-amplifier through a long cable it is important that the return loss into the receiver is good. Poor return loss can result in group delay ripples which will lead to the same distortions mentioned in the phase linearity section. A return loss of at least 20 dB (VSWR@1.22:1) should be maintained at the RF input of the receiver as well as any other RF ports.*

**Video Specifications**

*Video specifications are fairly well outlined by the EIA, CCIR, and CCITT. Receivers which meet these recommendations will provide excellent video quality. In addition many articles exist which discuss video distortions.*[1,2,5]

**Audio Specifications**

*The main indicators of audio performance are audio gain/frequency response and harmonic distortion. Typical good performance numbers are ± .5 dB 50 Hz to 15 kHz gain/frequency response and less than 1% harmonic distortion.*

**Clean-Carrier S/N**

*It is important that the audio and video S/N ratio of a video receiver in the absence of any noise at RF is known as this determines the ultimate S/N ratio achievable in a receiver. Good receiver designs will realize weighted S/N ratios in excess of 70 dB without any thermal noise.*

**Secondary Specifications** *Specifications are sometimes given which at first glance appear to be far superior to any other receiver but turn out to add very little to system performance or flexibility.*

**Receiver Noise Figure** *System noise figure (or noise temperature) is almost totally determined by the antenna, pre amp and associated components. As the calculations in Appendix A show for a system with a 10 meter antenna and a 50 dB pre amp with a 2.6 dB noise figure the difference between system noise temperature (and therefore G/T) of a receiver with a noise figure of 8 dB and one with a 14 dB noise figure is extremely small. A similar case exists for a pre amp with 40 dB of gain. Table 1 summarizes these results.*

| | Preamp Gain | System Noise Temp (dB) |
|---|---|---|
| *RX N.F. 8 dB* | *50* | *25.070* |
| *RX N.F. 14 dB* | *50* | *25.072* |
| *RX N.F. 8 dB* | *40* | *25.075* |
| *RX N.F. 14 dB* | *40* | *25.090* |

**Table 1 Noise Temperature Comparisons of 8 dB and 14 dB Noise Figure Receivers**

**AGC Range (Dynamic Range)** *A sufficient AGC range required to account for system gain variations and changes in receive signal strength after a system has been installed is on the order of 10 dB. Some receiver designs use the dc voltage that controls the gain of the receiver to drive a signal strength or carrier-to-noise (C/N) meter. To get good C/N readings the metering has to be zeroed-on-noise. For a maximum C/N of 20 dB a minimum of 20 dB AGC range would be required to AGC on noise. Allowing an additional 10 dB for gain variations in system design a 30 dB AGC range would be more than sufficient to handle most system requirements. There are very few systems that require 40 dB of gain range and gain ranges above 40 dB add almost nothing to system flexibility.*

## Misleading Specifications

**Video S/N** *The video S/N ratio above the threshold of the demod is totally controlled by the carrier-to-noise power density ratio, and the deviation. In addition, S/N is usually weighted by standard recommended weighting networks. S/N must be specified with respect to these parameters or it is a meaningless number.*

**Demodulator Threshold Performance**

*Demodulator threshold is variously defined as that C/N at which barely noticeable impulse noise occurs or that C/N at which the S/N deviates from a linear curve by a certain number. The two levels are quite different and the definition of threshold along with the modulation and weighting parameters must be defined to make this specification meaningful.*

*Also, it is important that video threshold measurements are performed with modulation since modulation tends to aggrevate S/N performance at threshold.*

*As a point of interest, Scientific-Atlanta's 411 Receiver was compared with 14 competitive video receivers by a customer to determine threshold performance superiority. It was found that Scientific-Atlanta's receiver had the best performance at threshold.*

## DESIGN TRADEOFFS

**Dual Conversion vs. Single Conversion**

*One question that is commonly raised is what are the advantages of dual conversion over single down conversion receivers. The basic difference between dual conversion and single conversion is in the number of intermediate frequencies (IF) and local oscillators (LO's). Single conversion uses one LO to convert directly to the final IF frequency (usually 70 MHz) and dual conversion uses two LO's to convert to two IF frequencies the final one which is also 70 MHz.*

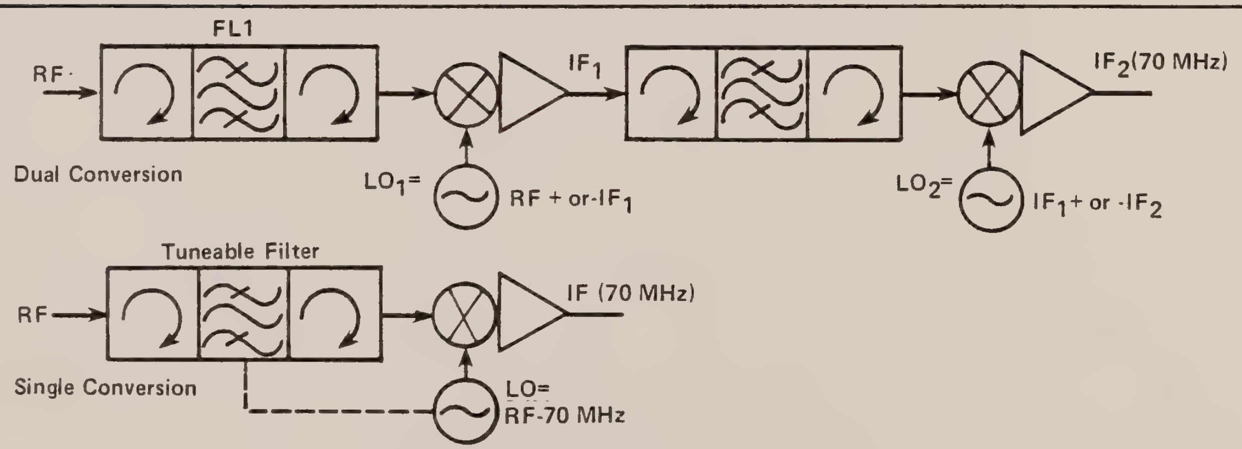



Figure 5. Dual and Single Conversion Downconverters

*As Figure 5 shows, the advantage of single conversion over dual conversion is cost. There is one fewer source, one less filter, one less mixer, and less gain is required (the loss of the second filter and mixer does not have to be made up). In a single conversion receiver, unless the IF frequency is well above the RF bandwidth (500 MHz) the input filter must be retuned either mechanically, electronically, or manually in addition to changing the LO frequency every time the receiver is required to select a different channel. Since the conventional final IF frequency for video receivers is usually 70 MHz, the discussion will continue assuming this 70 MHz as the single and dual conversion final IF frequencies.*

*The front end filter must provide rejection of the LO which is only 70 MHz from the RF frequency, as well as provide extremely good adjacent channel rejection. LO rejection becomes extremely important if two receivers are operated through a power divider from the same pre amp.*

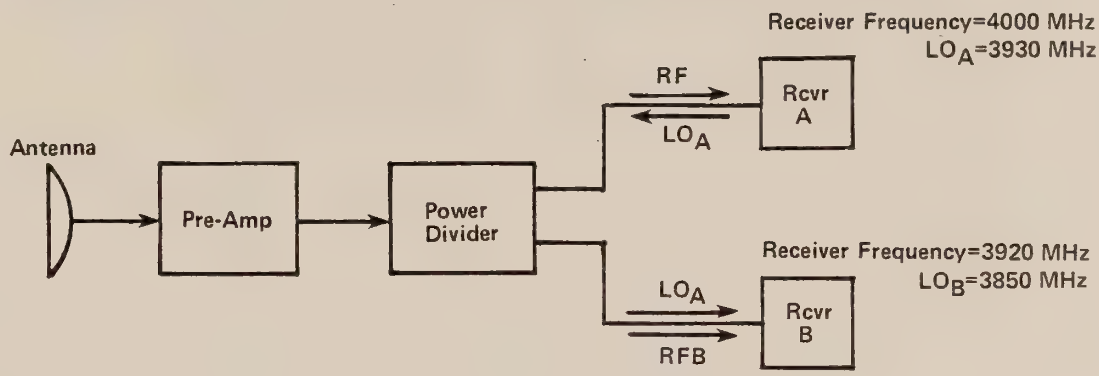



**Figure 6. Single Conversion LO Interference**

*Assuming a power divider port-to-port isolation of 20 dB, an LO power of +10 dBm in receiver A and an RF level into receiver B of -50 dBm, the down-converter of receiver A must have an LO rejection of -90 dB to reduce the LO leaking back to receiver B to 50 dB below the carrier. This can be done with a combination of isolators, filter rejection and mixer LO to RF isolation.*

*In a dual conversion receiver the first LO is chosen well above the RF bandwidth (around 1 GHz) and the LO frequency never falls within the RF passband.*

*Another requirement on the front end filter of a single conversion down-converter is to reject adjacent channels especially the LO -70 MHz frequency (image frequency). In a dual conversion receiver this must also be accomplished in the first IF filter. The image frequency of the input to the receiver in a dual conversion unit is out of the passband and with an LO on the order of 1 GHz filtering of the image frequency is considerably easier.*

*The important item to be considered is that in a dual conversion system all filtering is fixed while the filter must be tuned in the single conversion receiver for a different RF frequencies. If filter tracking is not precise, the group delay due to the input filter will change causing variations of video performance at different RF frequencies. In a dual conversion receiver the video performance will be identical to any RF frequency because all filtering is fixed.*

*Another potential disadvantage to single conversion as discussed here is switching time to another RF frequency in an automatic protection system. In a dual conversion system the switching time is limited to the time it takes the first LO to lock to a new reference frequency (typically less than 50 ms) while in a single conversion system the front-end filter must also be retuned. If filter tuning is done electronically or electro-mechanically, the time required to tune a new channel can be several times that required in a dual conversion downconverter.*

**Crystal or Synthesizer Controlled LO's Vs. Automatic Frequency Control (AFC)**

*Any noise present on the local oscillators (LO) will translate directly to the incoming signal. The purest LO is one that is crystal controlled. A receiver using AFC to control the LO is more likely to have power supply noise and amplifier noise cause modulation of the LO which will then be demodulated and can contribute significantly to clean-carrier S/N.*

## SCIENTIFIC-ATLANTA's 411 RECEIVER

**Introduction**

*The 411 receiver is a multi purpose satellite communications receiver that is used to process both FDM/FM (12-1800 channels) and video (any format) satellite transmission. The flexibility of the receiver is illustrated by the over 100 standard plug-in units that can be supplied to allow configuring the receiver for any standard satellite transmission without requiring any chassis interconnection changes. The extreme compactness and the modularity of the unit in addition to propriety designs have caused this receiver to be a top selection for world-wide and domestic earth stations. Scientific-Atlanta's experience in domestic video earth stations goes back to the first domestic video coast-to-coast transmission. This first system was a transportable station designed and manufactured for TelePrompter.*

**Receiver Discussion**

*A technical discussion of the modules that comprise a 411 video receiver is given in Appendix B. Figure 7 shows an overall receiver block diagram.*

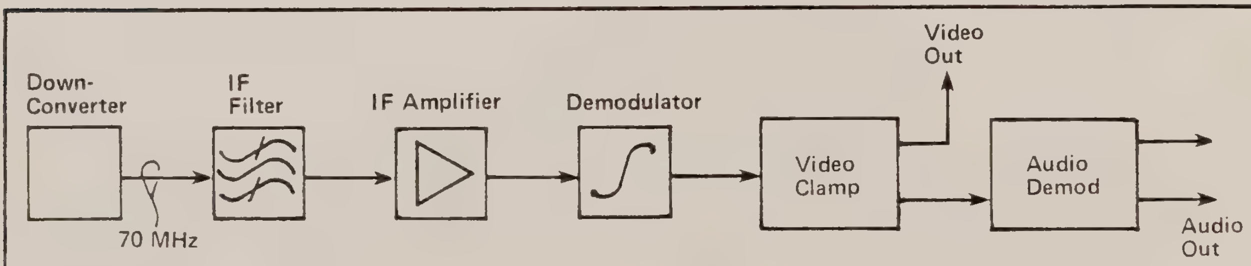



Figure 11. 411 Receiver Block Diagram.

*The RF signal is converted to a first IF frequency of 1112.5 MHz and then 70 MHz using high side LO's. Selection of the RF frequency is accomplished by changing the first LO frequency. The downconverter has an RF to IF gain of 20 dB. The signal is then injected into the 70 MHz IF filter which determines the IF bandwidth. The filter has a net gain of +8 dB. The IF amplifier provides the automatic gain control (AGC) in the receiver. It automatically adjusts its gain from 0 to +40 dB as required to provide a -5 dBm signal into the demodulator. The output of the demodulator is a pre-emphasized video signal with an output level set for 1.0V p-p at 761.6 kHz. The video clamp provides de-emphasis, removal of the dispersal waveform, restoration of the dc component of the video signal and removal of the subcarrier to provide the final video output. In addition, the clamp provides a de-emphasized composite signal to the audio subcarrier demodulator. The subcarrier demodulator demodulates the audio signal and provides a de-emphasized and filtered audio output.*

**411 Checkout and Testing**

*All modules are individually checked out before they are put into the receiver. The entire receiver is then burned in for approximately 1-2 weeks to reduce the probability of "infant" mortalities. After this burn-in period, receiver tests are run to check gain, gain/frequency response, group delay, and all video tests.*

**411 Maintenance Requirements**

*The only required maintenance on the 411 receiver is periodic video and audio output level checks.*

## APPENDIX A

*Calculation of the effect of receiver noise figure on system noise temperature and G/T*

*A typical receive earth station block diagram is shown in Figure 1A.*

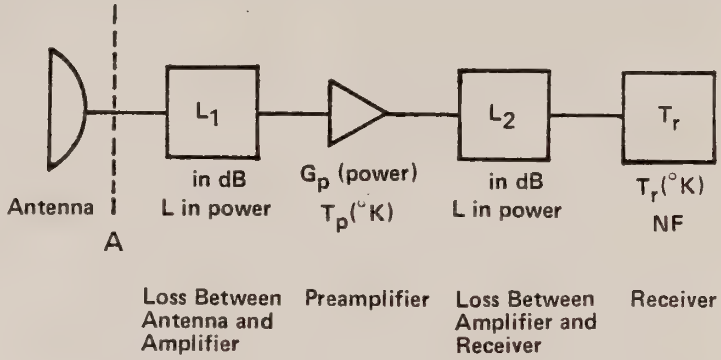



Figure 1A. Receiver Earth Station Block Diagram

*The defining equations required to calculate system noise temperature are as follows:*

**Dissipative Element** *The noise temperature of a dissipative element ($T_L$) is calculated using the formula*

$$T_L = (L - 1)\, T_o$$

*where $T_o$ = 290 °K, ambient temperature.*
*L = Power ratio of the loss of the dissipative element*

**Preamplifier** *An amplifier is usually defined by its noise figure, NF, which can be expressed in decibels or as a power ratio, and by its gain, also expressed in decibels or as a power ratio. The noise temperature and the noise figure of any device are directly related by the equation*

$$T(°K) = (NF - 1)\, T_o$$

*where NF is the noise figure (power ratio)*

*$T_o$ is the ambient temperature (290 °K)*

**Loss Between Preamplifier and Receiver** *The interconnecting cable between the preamplifier and the receiver contributes insertion loss, therefore noise, to the overall system. This noise term is calculated by the same method as the loss term above.*

**Receiver** *The receiver is usually defined by its noise figure, NF, either in decibels or as a power ratio.*

*NF (in power) = antilog* $_{10}$ *[NF (in dB)]*

*The noise contribution of this element is given by* $T(°K) = (NF\text{-}1)\ T_o$

*where NF is the noise figure (power ratio)*

$T_o$ *is the ambient temperature (290 °K)*

*Now that we have defined the individual parameters of the antenna system we can proceed to calculate the noise temperature of this system relative to point A. The following lists typical values for the system of Figure 1.*

| | | | |
|---|---|---|---|
| Antenna | Gain | = | 50.65 dBi |
| $(T_A)$ | Noise Temperature | = | 26 °K @ 20 ° el |
| Waveguide $(L_1)$ | Insertion Loss | = | 0.45 dB<br>1.1092 power ratio |
| Preamplifier $(G_p)$ | Gain | = | 50 dB<br>$10^5$ power ratio |
| $(NF_p)$ | Noise Figure | = | 2.6 dB<br>1.8197 power ratio |
| Cable (100′ of 7/8″) $(L_2)$ | Insertion Loss | = | 2.9 dB<br>1.95 power ratio |
| Receiver $(NF_r)$ | Noise Figure | | |

*System Noise Temperature referenced to point A.*

$$T_s = T_A + (L_1 - 1)\ T_o + L_1\ (NF_p - 1)\ T_o + \frac{L_1\ (L_2 - 1) T_o}{G_p} + \frac{L_1 L_2\ (NF_r - 1)\ T_o}{G_p}$$

$$T_s = 26 + (1.1092\text{-}1)290° + 1.1092\ (1.8197\text{-}1)290 + \frac{1.1092(1.95\text{-}1)290}{G_p}$$

$$+ \frac{(1.1092)\ (1.95)\ (NF_r - 1)\ (290°}{G_p}$$

$$T_s = 321.339 + \frac{(305.58 + 627.25\ (NF_r - 1)}{G_p}$$

*For a preamp gain of 50 dB (power ratio of $10^5$) a calculation of an 8 dB noise figure (power ratio 6.31) receiver versus a 14 dB noise figure (power ratio of 25.12) yields*

$T_{s/8} = 321.375\,^\circ K \quad 10 \log T_s = 25.070$ dB

$T_{s/14} = 321.493\,^\circ K \quad 10 \log T_s = 25.072$ dB

*For a preamp with 40 dB gain (power ratio of $10^4$)*

$T_{s/8} = 321.702 \quad 10 \log T_s = 25.075$ dB

$T_{s/14} = 322.882 \quad 10 \log T_s = 25.090$ dB

*G/T is used to compare receive earth station performance. The figure of merit, G/T, is defined as the ratio of the power gain of an antenna system referenced at some convenient point to the noise temperature in °K of the antenna system referenced at the same point. If this ratio is to be expressed in decibels, then the following calculation is valid*

$$G/T = \frac{\text{Gain of antenna (power ratio)}}{\text{Noise temperature of antenna system } (^\circ K)}$$

$$10 \log G/T = 10 \log G - 10 \log T_s$$

*or*

$$G/T \,\big|\, dB = 10 \log G - 10 \log T_s$$

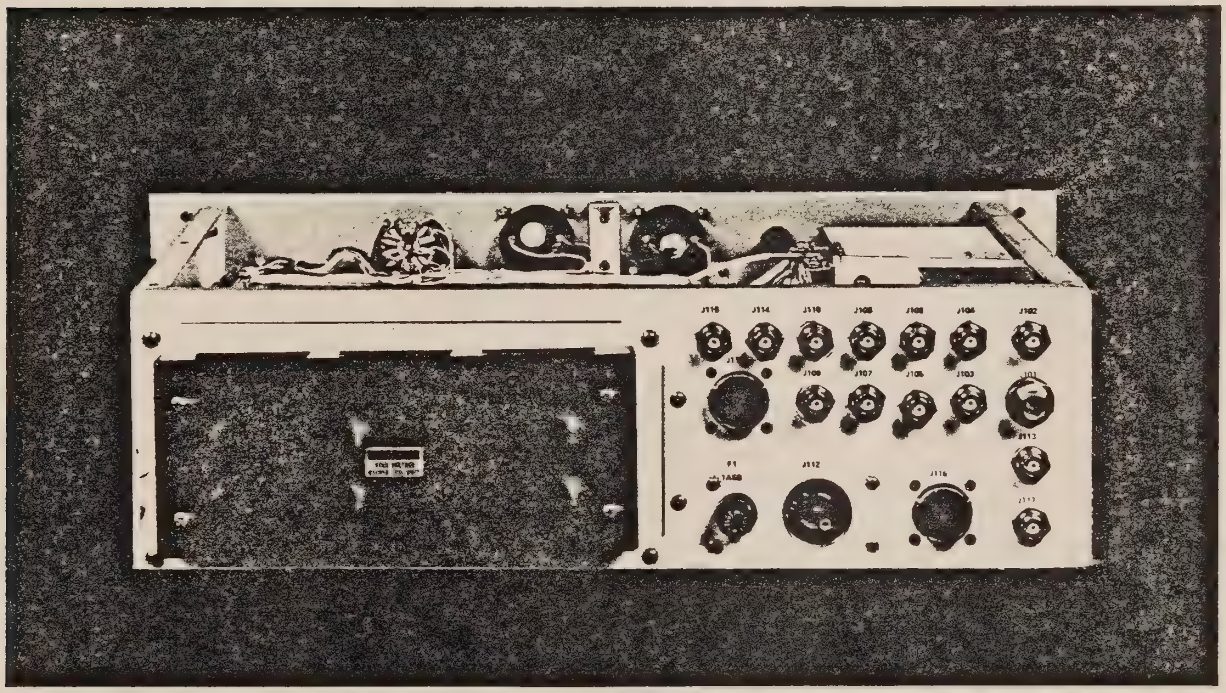
*The change of G/T using an 8 dB noise figure receiver versus a 14 dB noise figure is only .015 dB for a 40 dB pre amp and .002 dB for a 50 dB pre amp.*

## APPENDIX B - 411 Receiver Module Technical Information

**Series 411 Mainframe - Part No. 129106**

*The mainframes for the receivers are standard 19-inch rack mounted designs that are 5.25 inches high. The mainframe is a U-shaped aluminum chassis with an integral rear panel that contains all input/output connections as well as ac power-line fuse. All operating controls are located on the front panel.*

*Internal wiring for all receiver configurations is identical. DC operating voltages are carried to the interface connectors of all modules, whether or not a module is inserted. Signal input and output interconnections are made via the rear-panel (see Photo No. 8489) connectors so that, with the appropriate external patch cables connected, the modules in any configuration will be properly interconnected. Rear-panel patches are also furnished for such signals as the 70 MHz IF and first local oscillator to permit access to these signals for system testing and/or calibration.*



Model 411WB Rear Panel, Photo No. 8489

*Signal flow through the receiver is quite straightforward and is illustrated by the functional block diagram of the mainframe (Figure 1B.)*

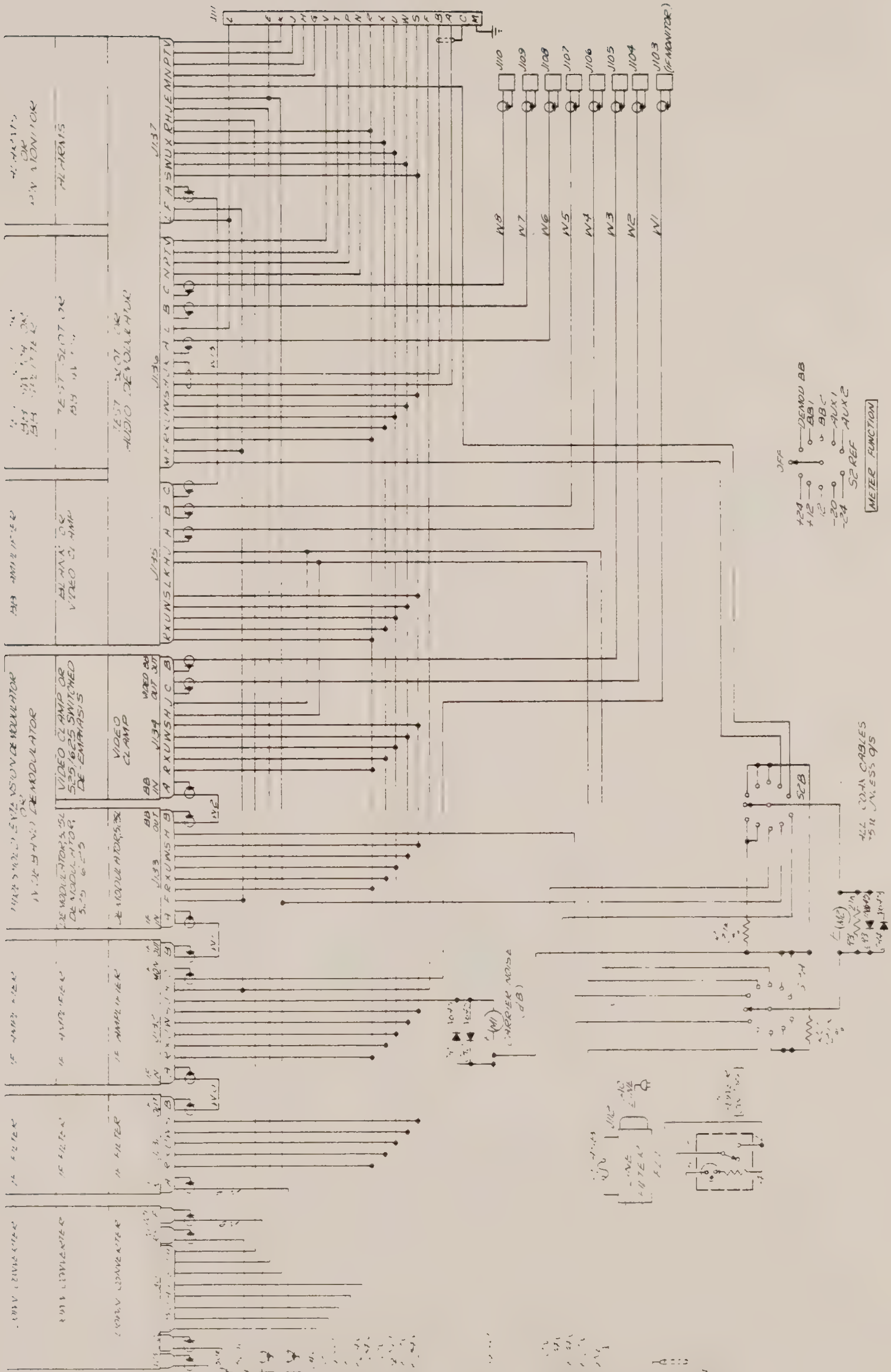



Figure 1B. Series 411WB-( ) Receiver Mainframe

*The left-hand section of the units is always reserved for the frequency converter which is a chassis subassembly. The right section of the mainframe provides slide-in mounting facilities for the IF and baseband processing modules. Machined tracks in a plate at the bottom of the chassis guide and modules smoothly into position so they will positively mate with interface connectors on a bracket near the rear of the chassis. One important feature of Scientific-Atlanta's GCE is that the second slot from the right, with the mainframe viewed from the front, can be used as a test slot. The pins of the interface connector on the module plugged into the test slot are brought out to the rear of the chassis. In this way, the power supply can be used to power the module while it is under test. The unit may or may not be operational, however, under these conditions.*

*The Model 402A Power Supply is a plug-in unit that furnishes dc power to modules of the Scientific-Atlanta Series 400 Receiver equipment. Four voltages are produced: +24V dc, +12V dc, -24V dc, -12V dc. Current limiting is furnished for all four supplies; overvoltage protection in the form of a crowbar circuit is provided on the 12 volt supplies.*

*Ripple and noise on the output of the supplies is typically less than 10mV peak-to-peak for the 24 volt supplies, and 5mV peak-to-peak for the 12 volt supplies. Total load and line regulation for all supplies is typically less than 0.5%. This unit mounts on the rear apron of each chassis.*

*With regard to controls/metering of the receivers and exciters, the units have the power on/off control, a meter for signal level indication and a multi-function meter with associated function switch. The following tabulation provides the characteristics of the controls and metering.*

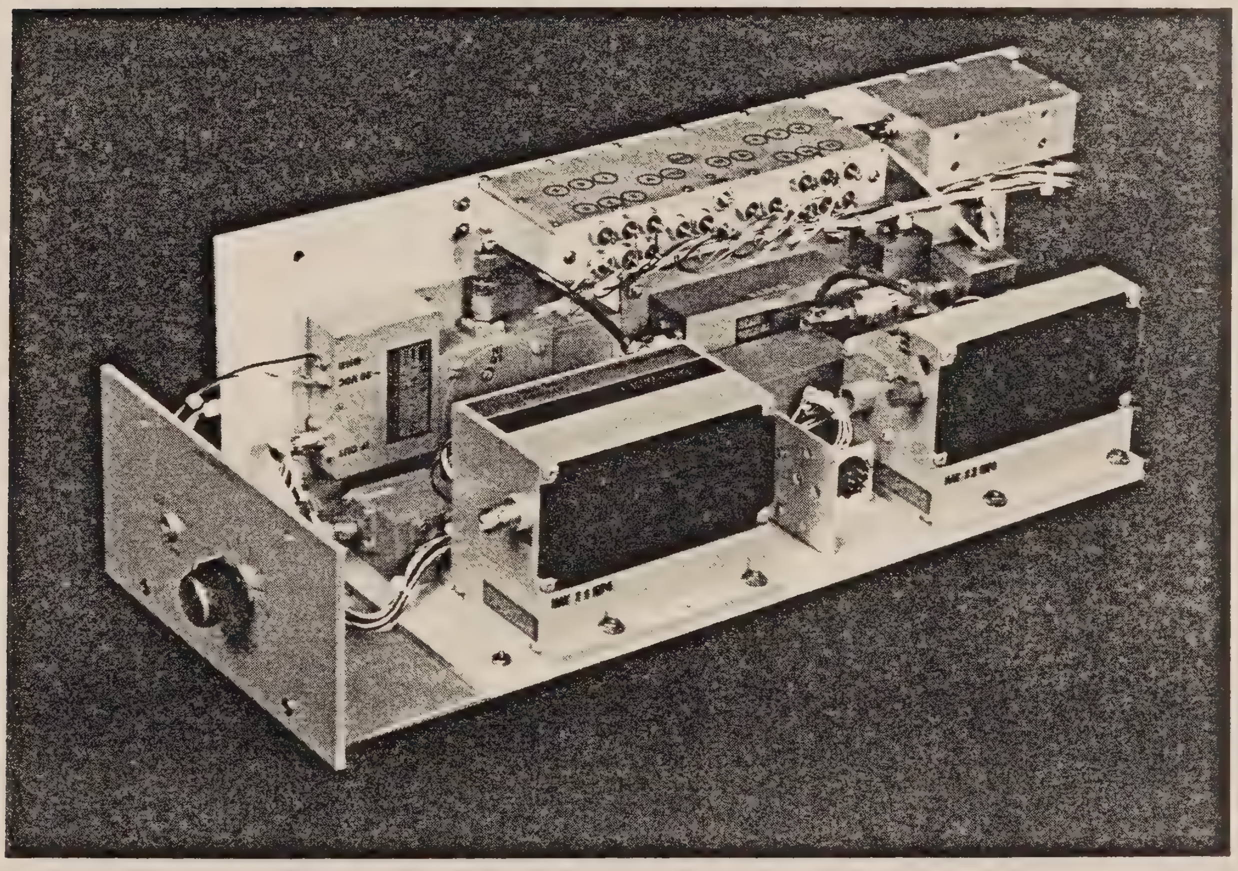
| Control/Indicator | Position | Function |
|---|---|---|
| *Power ON/OFF switch* | *ON (lit )* | *AC power applied to receiver* |
| | *OFF (dark)* | *AC power removed from receiver* |
| *METER FUNCTION switch* | *OFF* | *Meter disconnected* |
| *(Used in conjunction with multi-function meter next to switch)* | *-24* | *Meter reads voltage on receiver -24V dc bus* |
| | *-20* | *Meter reads output from -20V dc supply in downconverter (derived from receiver -24V dc bus)* |
| *NOTE: Read voltages on top meter scale.* | *-12* | *Meter reads voltage on receiver -12V dc bus* |
| | *+12* | *Meter reads voltage on receiver +12V dc bus* |
| | *DEMOD BB<br>BB 1<br>BB 2<br>AUX 1<br>AUX 2* | *These switch positions connect the meter to read various baseband and video levels at the outputs and inputs of the modules plugged into the mainframe.* |
| *CARRIER/NOISE meter* | *——* | *Gives an indication of the ratio of carrier to noise. The meter actually reads (carrier + noise)/noise, and at very low carrier levels will read a little higher than the actual carrier level. At higher levels, however, noise contribution to the meter reading is insignificant.* |

TABLE 1B. - Receiver Mainframe Controls and Indicators

**Frequency Downconverter - Part No. 127235**

*The downconverter to be utilized in the message and video receivers is Scientific-Atlanta's Standard Model 411WB(D) 3.7-4.2-0. This unit mounts into the mainframe in the extreme left-hand position and receives its power from the mainframe.*

*The Model 411WB(D) 3.7-4.2-00 Downconverter is a dual conversion frequency agile unit that is utilized in Scientific-Atlanta's satellite communication message and video receivers. The input frequency is in the 3.7-4.2 GHz band and the output is a 70 MHz IF signal. The standard version has the capability of reception at any one of 12 switch-selectable frequencies. Remote Freguency selection is available as an option as well as a built-in frequency synthesizer. Photo No. 6632 shows the module which is held into the mainframe with four screws. RF connections to the downconverter are made on the rear panel of the mainframe. Also provided on the rear panel are the first LO signal and the main IF signal output. Patch cables furnished with the receiver complete the circuits for standard operation.*



Model 411WB (D) 3.7-4.2 Downconverter Module, Photo No. 6632

*The function of the downconverter is to select the desired receive channel frequency and convert the incoming signal to an IF of 70 MHz. This is accomplished in two frequency conversions. The first conversion is to an IF of 1112.5 MHz. At this IF, signals are amplified, filtered, and then further converted to 70 MHz. Figure 2B is a functional block diagram.*

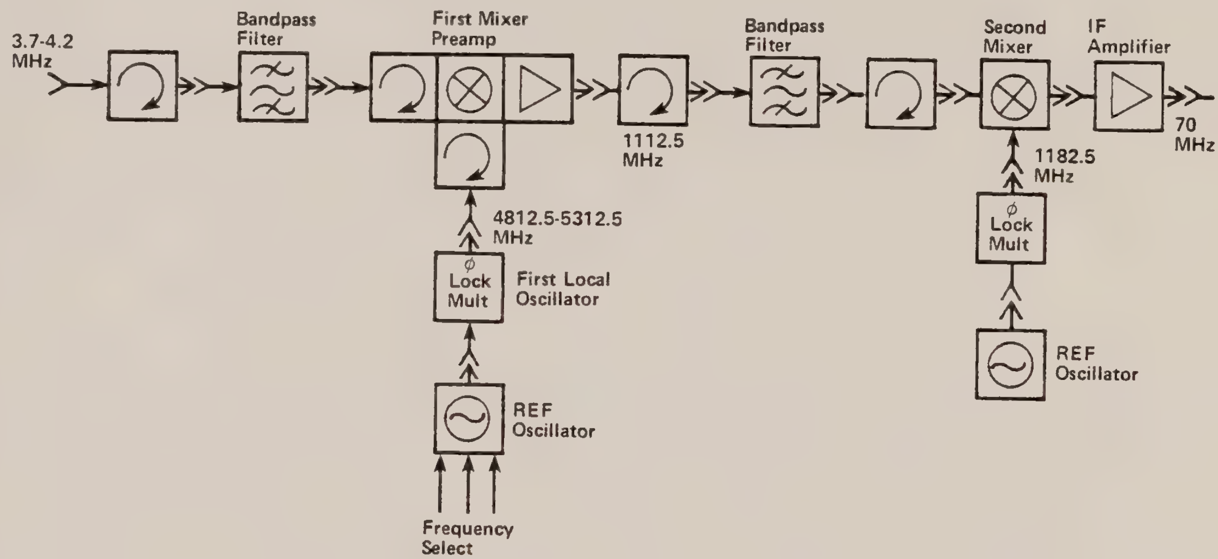



Figure 2B. Series 411 Dual Conversion Downconverter.

*Signals entering the downconverter first pass through an input bandpass filter which has a passband from 3.7-4.2 GHz. It's function is to provide image rejection for the first conversion and rejection of out-of-band signals while passing all in-band received signals to the first-mixer preamplifier unit. The mixer-preamplifier selects the desired signal within the 3.7 to 4.2 GHz band according to the frequency supplied by the local oscillator and multiplier units.*

*The local oscillator provides frequencies from 4.81 to 5.31 GHz. The local oscillator frequency is determined by a switch-selectable crystal oscillator by an external source, or by an internal synthesizer.*

*The reference oscillator operates in the 100- to 110 MHz region and serves as a reference frequency for phase-locked multiplier. The multiplier provides a net frequency multiplication of 48 and provides sufficient power output in the 4.8 - 5.3 GHz range to drive the first mixer.*

*The desired signal ($f_o$) is selected by applying a local oscillator frequency of ($f_o$ + 1112.5) MHz to A1, which results in the desired signal being converted to an IF of 1112.5 MHz. The reference oscillator frequency is determined by the relationship*

$$F_{ref} = \frac{F_{rx} + 1112.5}{48}$$

*After mixing and conversion to the 1st IF of 1112.5 MHz, a preamplifier in the mixer preamplifier assembly amplifies the signal and sets the noise figure of the downconverter.*

*Following the preamplifier the desired signal is filtered to a bandwidth of 40 MHz, which serves to suppress adjacent channel signals and provides image rejection for the second mixer. The second mixer provides the final conversion to the 70 MHz IF. The local oscillator for this conversion to 70 MHz, an output amplifier provides approximately 11 dB of gain at 70 MHz.*

*Figure 3B shows gain distribution in the downconverter.*

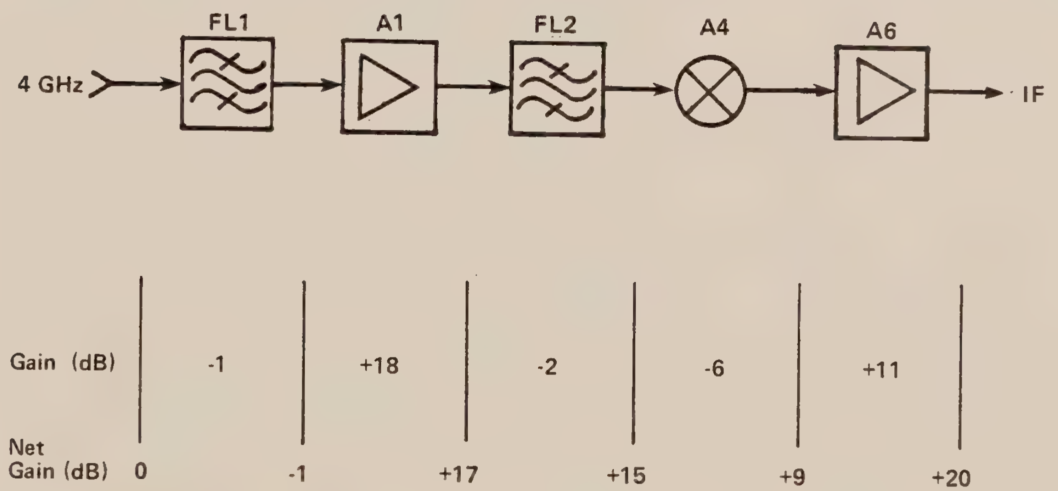



Figure 3B. Downconverter Gain Distribution.

*All operating controls are provided on the front panel of the unit:*

**Frequency Select** *The Frequency Select switch is used to select the frequency to be received. In the standard downconverter, the switch positions are marked 1 through 12. Refer to the Test Data section of this instruction manual for a cross reference from switch position to frequency.*

**LO Select** - *During normal operation, the LO Mode switch is left in the Local position, and the frequency of the 1st LO is determined by the front-panel Frequency Select switch. In the Remote position, 1st LO frequency is determined by an external source, external switch, or internal synthesizer.*

| Characteristic | Specification |
|---|---|
| *Input* | |
| *Frequency* | *3700 to 4200 MHz* |
| *Level* | *-20 dBm max* |
| *Impedance* | *50 ohms* |
| *Return Loss* | *23 dB* |
| *Noise Figure* | *14 dB maximum, 12 dB typical* |
| *Output* | |
| *Frequency* | *70 MHz ±20 MHz* |
| *Impedance* | *75 ohms (unbalanced)* |
| *Return Loss* | *Greater than 23 dB from 50 MHz to 90 MHz* |
| *Image Attenuation* | *80 dB minimum* |
| *Local Oscillator Leakage* | *-80 dBm maximum at RF input* |
| *RF-IF Gain* | *20 dB nominal* |
| *Gain Response* | *±0.25 dB, $f_o$ ±18 MHz* |
| *IF Bandwidth* | *40 MHz, minimum* |
| *Delay Distortion* | |
| *Linear* | *Less than ±0.03 ns/MHz, $f_o$ ±18 MHz* |
| *Parabolic* | *Less than 0.01 ns/MHz$^2$, $f_o$ ±18 MHz* |
| *Ripple* | *Less than 1.0 ns peak-to-peak, $f_o$ ±18 MHz* |
| *Third-Order Distortion* | *Greater than 50 dB below the desired carrier level when driven by two equal carriers at the RF input at -30 dBm each* |
| *Spurious Responses* | *65 dB below desired signal* |
| *Local Oscillators* | |
| *Standard* | |
| *Frequencies* | *12 Switchable* |
| *Stability* | *1 part in $10^6$/day (25 °C)*<br>*2 part in $10^7$/°C (0-50 °C)* |
| *Optional* | |
| *Frequencies* | *1 to 12 as specified* |
| *Stability* | *±200 Hz/day (15-35 °C)* |

Table 2B. Downconverter Technical Characteristics.

**IF Filters** *The IF Filters (see Photo No. 6623) are front panel plug-in modules for operation with the Series 411 Receivers and Series 461 Exciters. These units plug into specific slot assignments of the mainframe and receivers operating power from the mainframe power supply. Connections are made to the filter through an interface connector on the rear of the module.*

*The purpose of the filter is to provide rejection of unwanted out-of-band signals and to provide amplification of the desired in-band signals. In addition, equalization of group delay due to the filter is provided. The following is a block diagram of the IF filter.*


Figure 4B. IF Filter Block Diagram.

*The technical characteristics of the IF filters are listed in the following table:*

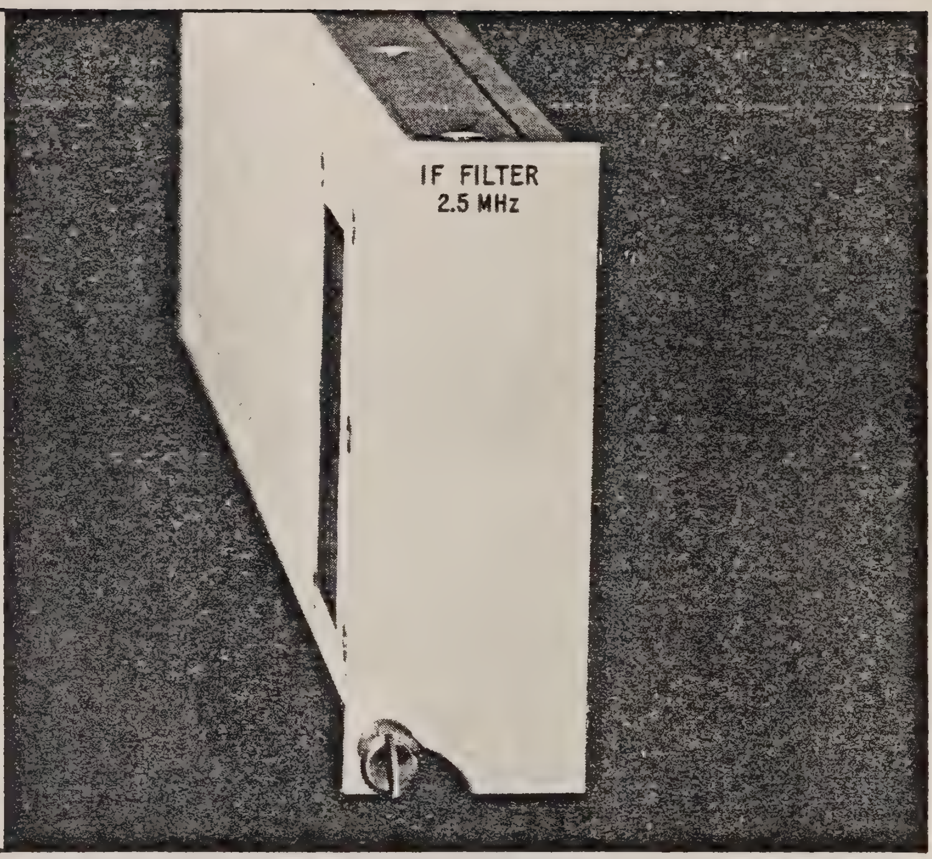
| BW (MHz) | Max Input Level | Receiver Gain | Exciter Gain |
|---|---|---|---|
| **Narrow Band Filters** | | | |
| 2.5 | -24.6 dBm | 19.8 ±1 dB | 8 ±2 dB |
| 5.0 | -21.6 dBm | 16.6 ±1 dB | 8 ±2 dB |
| 7.5 | -19.8 dBm | 14.8 ±1 dB | 8 ±2 dB |
| 10 | -18.6 dBm | 13.6 ±1 dB | 8 ±2 dB |
| **Wideband Filters** | | | |
| 15.0 | -16.8 dBm | 11.8 ±1 dB | 8 ±2 dB |
| 17.5 | -16.1 dBm | 11.1 ±1 dB | 8 ±2 dB |
| 20.0 | -15.6 dBm | 10.6 ±1 dB | 8 ±2 dB |
| 25.0 | -14.6 dBm | 9.6 ±1 dB | 8 ±2 dB |
| 30.0 | -13.8 dBm | 8.8 ±1 dB | 8 ±2 dB |
| 36.0 | -13.0 dBm | 8.0 ±1 dB | 8 ±2 dB |

*1.25 MHz Bandwidth Filters are now being added.

Table 3B. IF Filter Characteristics.

*IF filter amplitude and delay characters are shown in Figures 5B and 6B.*

IF Filter Module
Photo No. 6623



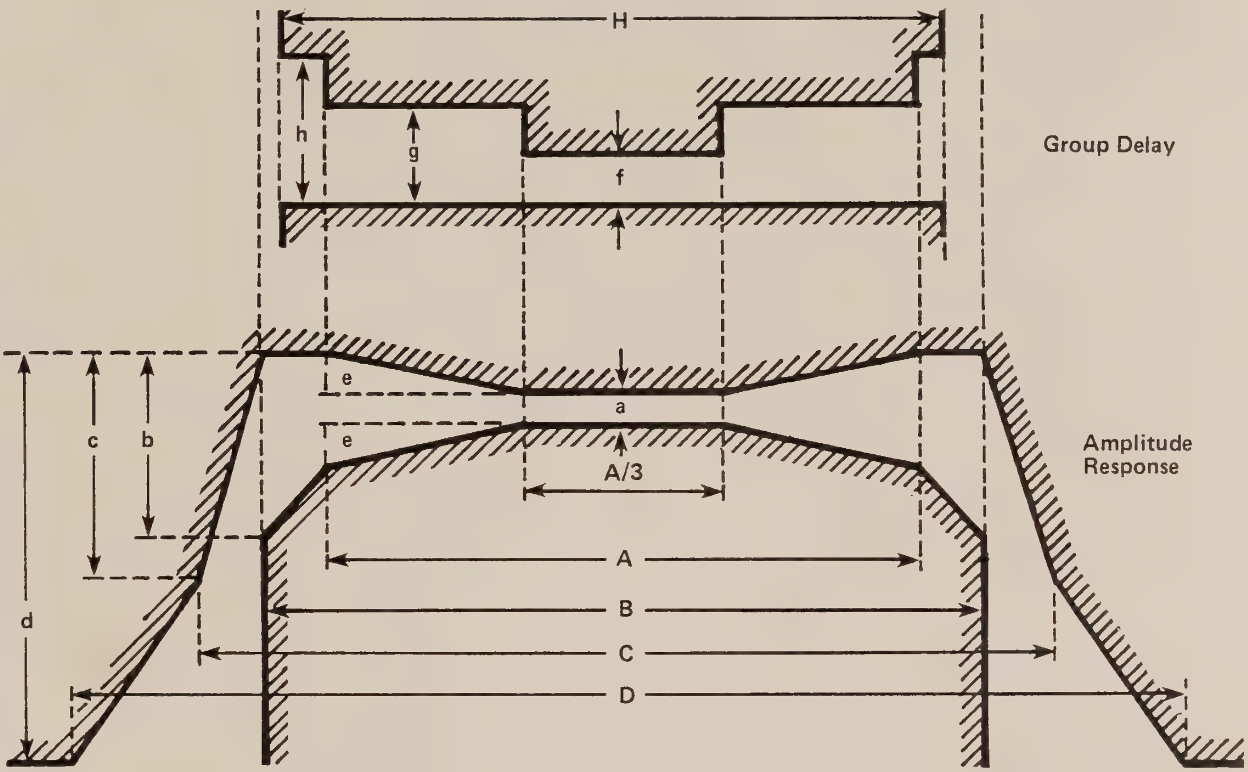



Figure 5B. IF Filter Amplitude-Delay Characteristics

| S-A Part No | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131621 | 2.5 | 1.8 | 2.25 | 2.75 | 8.0 | 0.7 | 1.5 | 2.5 | 25 | 0 | 2.1 | 16 | 16 | 20 |
| 131622 | 5 | 3.6 | 4.5 | 5.25 | 13.0 | 0.5 | 2.0 | 3.0 | 25 | 0 | 4.1 | 12 | 12 | 20 |
| 131623 | 7.5 | 5.4 | 6.75 | 7.75 | 17.0 | 0.4 | 2.5 | 4.0 | 25 | 0 | 6.2 | 12 | 12 | 20 |
| 131624 | 10 | 7.2 | 9.0 | 10.25 | 19.0 | 0.3 | 2.5 | 5.0 | 25 | 0.1 | 8.3 | 9 | 9 | 18 |

| S-A Part No. | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131625 | 15 | 10.8 | 13.5 | 15.5 | 25.0 | 0.3 | 2.5 | 5.5 | 25 | 0.1 | 12.4 | 6 | 6 | 15 |
| 131626 | 17.5 | 12.6 | 15.75 | 18 | 26.5 | 0.3 | 2.5 | 6.5 | 25 | 0.1 | 14.2 | 6 | 6 | 15 |
| 131627 | 20 | 14.4 | 18.0 | 20.5 | 28.0 | 0.3 | 2.5 | 7.5 | 25 | 0.1 | 16.6 | 4 | 5 | 15 |
| 131628 | 25 | 18.0 | 22.5 | 25.75 | 34.0 | 0.3 | 2.5 | 8.0 | 25 | 0.2 | 20.7 | 3 | 5 | 15 |
| 131930 | 36.0 | 28.8 | 36.0 | 45.25 | 60.0 | 0.6 | 2.5 | 10.0 | 25 | 0.3 | 33.1 | 3 | 5 | 15 |
| 131929 | 30 (video) | 24.0 | 30.0 | – | – | 0.5 | 2.5 | – | – | 0.3 | 30.0 | 5 | 5 | 15 |

Figure 5B. IF Filter Amplitude-Delay Characteristics.

**IF Amplifier - Part No. 127183**

*The IF amplifier (see Photo No. 6622) is a front panel plug-in module for utilization in the Series 411 Receivers. The unit is all solid-state and receives its operating power from the mainframe assembly.*

*The purpose of the IF amplifier is to provide signal amplification at the IF frequency of 70 MHz and to provide automatic gain control of the signal. This feature presents a constant 70 MHz input level to the circuits that follow. A block diagram of the IF amplifier is shown in Figure 7B.*

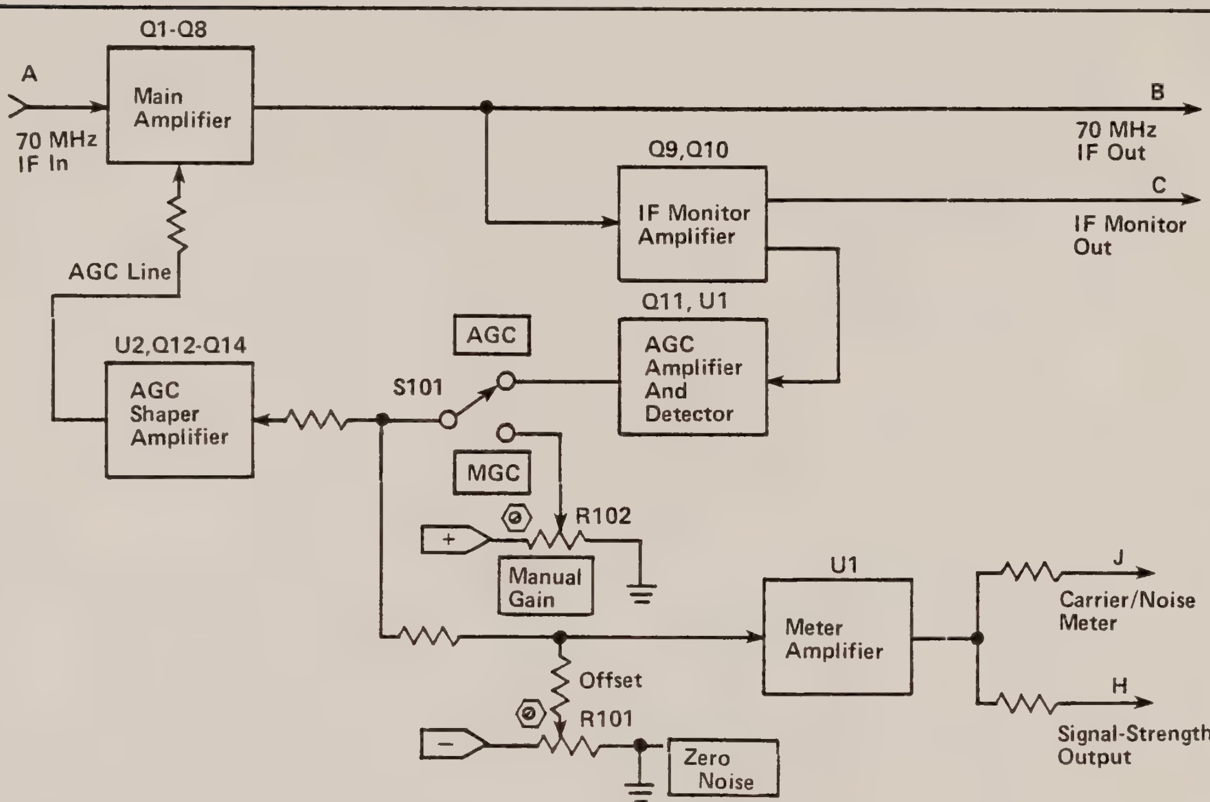
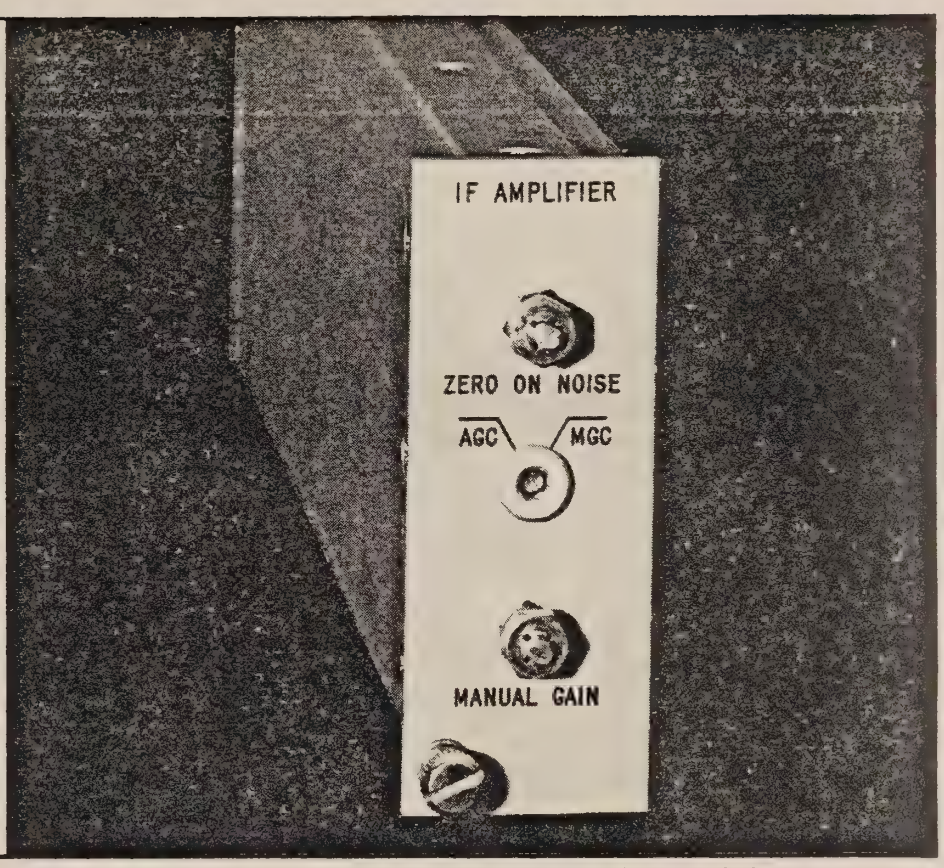



Figure 7B. IF Amplifier Block Diagram.

IF Amplifier Module
Photo No. 6622




*The following table provides the overall technical characteristics*

| Characteristics | Specification |
|---|---|
| **Input** | |
| *Frequency* | *70 ±20 MHz* |
| *Impedance* | *75 ohms unbalanced* |
| *Return Loss* | *>23 dB* |
| *Level* | *–5 dBm max* |
| **Output** | |
| *Impedance* | *75 ohms unbalanced* |
| *Return Loss* | *>20 dB* |
| *Level* | *–5 dBm (with AGC)* |
| **Gain** | |
| *AGC or MGC* | *0 to +40 dB* |
| *Flatness* | *0.5 dB peak-to-peak* |
| **Group Delay** | *<0.5-ns variation* |
| **Monitor Output** | |
| *Impedance* | *75 ohms unbalanced* |
| *Return Loss* | *<20 dB* |
| *Level* | *Within 1 dB of main output* |

Table 4B. IF Amplifier Technical Characteristics.

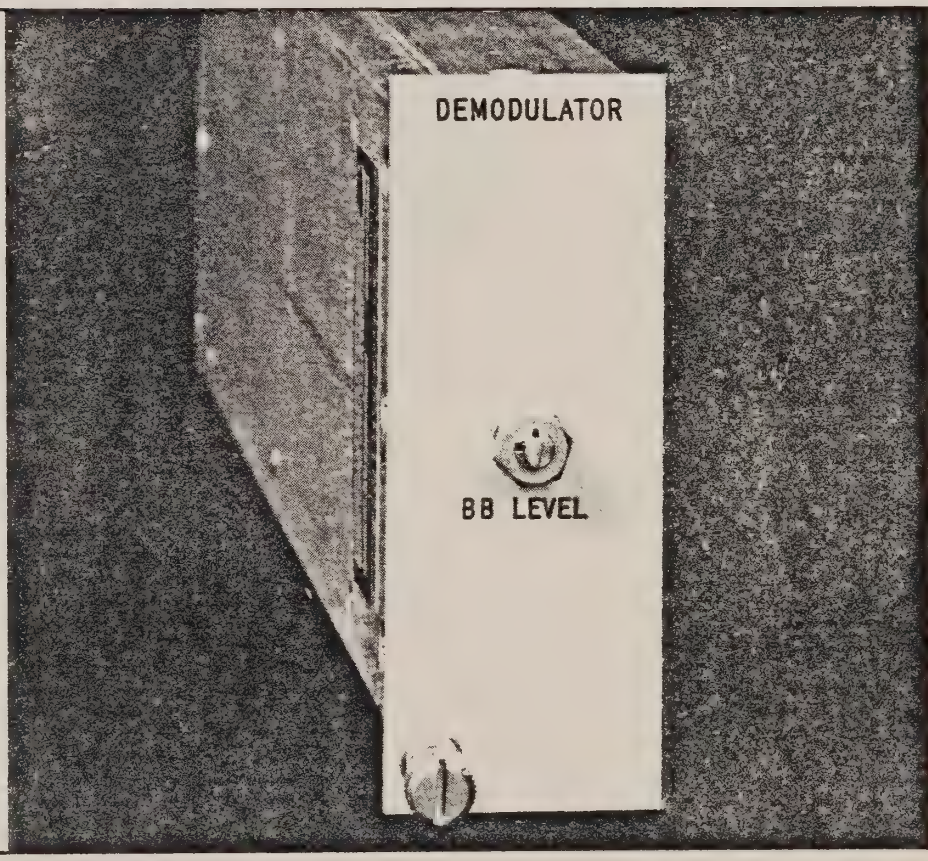
**Wideband FM Demodulator - Part No. 131675**

*The purpose of the wideband demodulator is to recover wideband FM information and provide a multiplexed baseband signal at a -25 dBm level at the test tone frequency for 12 to 1872 channel message formats and 1 volt peak-to-peak signal at the test tone frequency for all video formats.*

*The wideband FM demodulator (Photo No. 8327) is a plug-in module intended for operation with Scientific-Atlanta Series 411 Receiver equipment. The demodulator provides discrimination of wideband frequency-modulated signals, and is specifically designed for use in satellite communications for both message (12 to 1872 channels) and video (all formats) reception. Below 600 channels, a threshold extension unit (Part No. 131615) may be used in conjunction with the demodulator.*

*Front-panel potentiometer R201 controls the final level out of the demodulator. Q20 is a peak detector which can be used to determine approximate video output levels as noted on the mainframe multifunction meter. The peak detector does not respond to message signals.*

Wideband Demodulator Photo No. 8327



| Characteristics | Specification |
|---|---|
| *Type* | *FM* |
| *IF Center Frequency* | *70 MHz* |
| *Input Impedance* | *75 ohms* |
| *Input Return Loss (70 ±18 MHz)* | *>26 dB* |
| *IF Limiting* | *15 dB minimum* |
| *IF Input Level* | *–5 dBm ±2 dB* |
| *Discriminator Linearity (70 ±18 MHz)* | *Better than 1%* |
| *Output Level* | |
| *Message* | *–25 dBm at test tone (TT) Deviation* |
| *Video* | *1.0V peak-to-peak at TT frequency* |
| *Frequency Response* | *±0.1 dB (15 Hz to 6 MHz)* |
| | *±0.2 dB (6 MHz to 8.2 MHz)* |

Table 5B. Wideband FM Demodulator Technical Characteristics.

**Video Clamp - Part No. 141458** *The video clamp module (Photo No. 8426) is a front panel plug-in unit for utilization in the Series 411. The primary purpose of this unit is to provide rejection of the triangular energy dispersal waveform; however, it also furnishes the baseband signal output for the audio subcarrier demodulator and provides a filtered and amplified video signal.*

*Figure 9B is a block diagram of the video clamp. The baseband output of the demodulator is fed to the 75-ohm input of the video clamp module.*

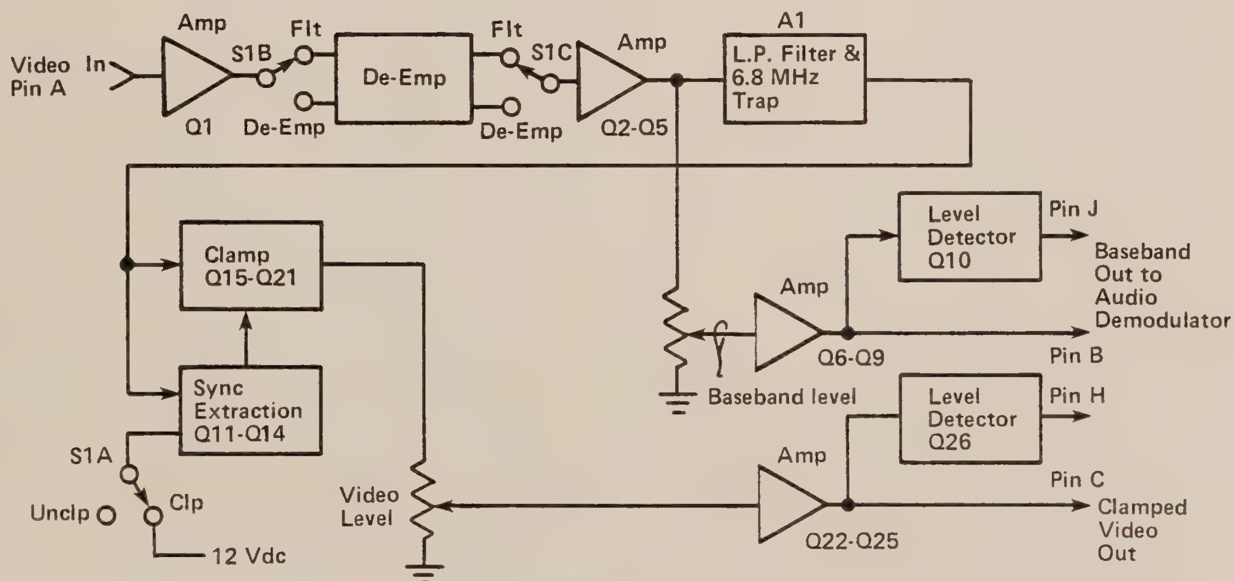



Figure 8B. Video Clamp Module Block Diagram.

*The baseband signal is buffered by emitter follower, Q1, which drives the de-emphasis network, A1. The de-emphasis network is selected for either 525-line or 625-line operation. The part number for 525-line de-emphasis is 141459. The part number for 625-line de-emphasis is 141460.*

*Front panel switch S1 selects either de-emphasis or flat response. In the flat position, a resistor network provides loss equivalent to the loss at the respective crossover frequency. The flat baseband signal is then amplified by amplifier Q2 through Q5. The signal at this point takes two routes. The baseband signal is amplified by the broadband amplifier stage Q6 through Q9 for use in the audio demodulator module. The nominal baseband output signal level is 1 volt peak-to-peak into 75 ohms. This level is adjustable with front panel potentiometer R24.*

*The signal also goes to the subcarrier trap and low pass filter A2. This plug-in module provides the necessary video-band limiting and 6.8 MHz rejection. The baseband signal then goes to Q11 and Q18 to remove the 30 Hz spreading waveform in order to provide excellent picture information.*

*Transistors Q11 through Q14 extract the sync tips from the video signal. Transistors Q15 through Q17 drive the diode gate CR6 through CR9, which turns on only during the sync-tip interval and clamps the sync tips at a ground level to remove the spreading waveform. Transistors Q18 through Q21 form an extremely high impedance, unity gain, broadband amplifier which is required for proper operation of the clamp circuit.*

*Following the amplifier is a broadband video amplifier, Q22 through Q25. The nominal video output level is 1 volt peak-to-peak into 75 ohms. This level is adjustable with front panel potentiometer R77.*

*Transistors Q10 and Q26 are peak detectors to allow monitoring video and baseband peak-to-peak output voltage levels on the mainframe multifunction meter.*

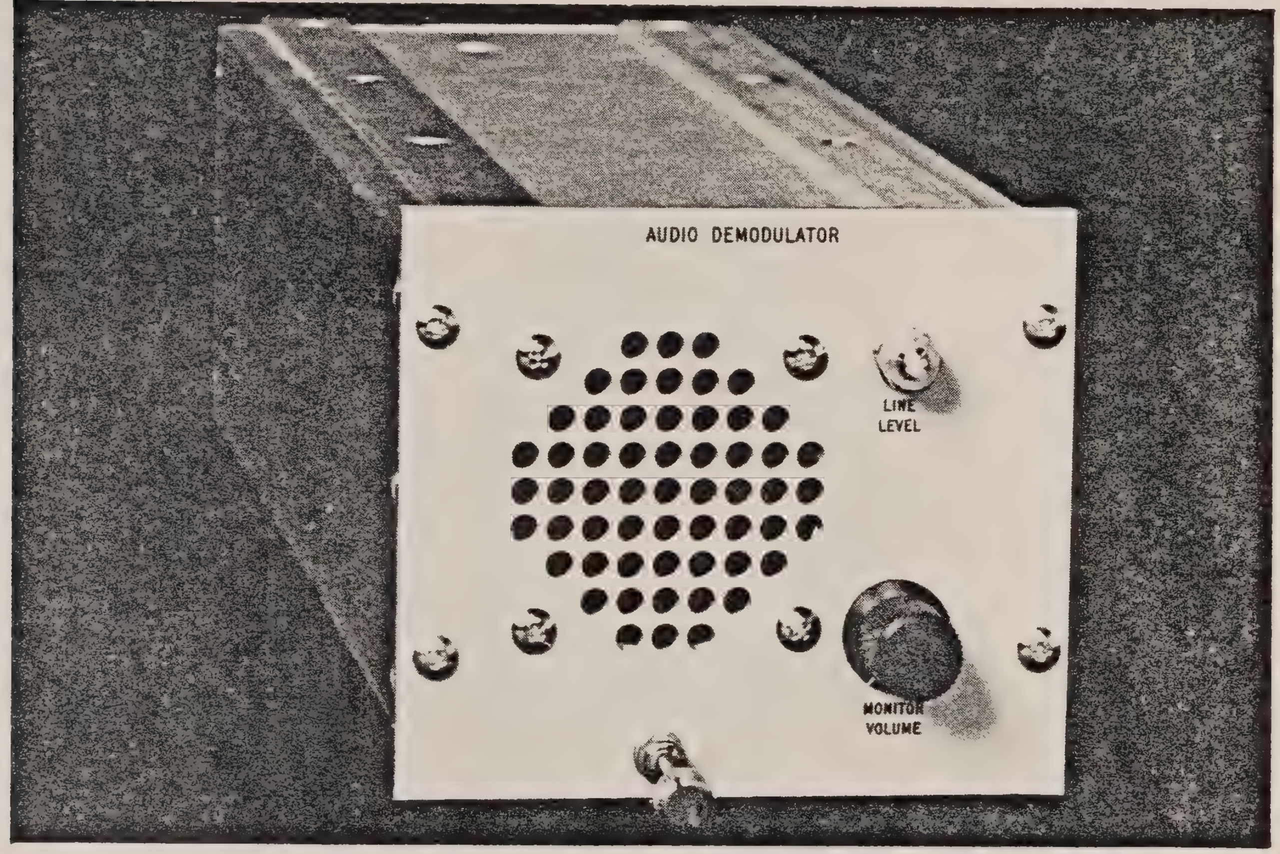
Video Clamp
Photo No. 8426


| **Characteristics** | **Specification** |
|---|---|
| *Input/Output Impedance* | |
| *Frequency Response* | *75 ohms unbalanced* |
| *Video Amplifier, 525 Line* | *±0.1 dB (15 Hz to 4.2 MHz)* |
| *Video Amplifier, 625 Line* | *±0.1 dB (15 Hz to 6.0 MHz)* |
| *Baseband Amplifier,* | *±0.2 dB (15 Hz to 6 MHz)* |
| *525 Line and 625 Line* | *±0.4 dB (6 MHz to 9 MHz)* |
| *Energy Dispersal Rejection* | *Greater than 50 dB* |
| *Audio Subcarrier Rejection* | *Greater than 30 dB* |
| *Nominal Input Level* | *1V peak-to-peak into 75 ohms* |
| *Nominal Output Level* | *1V peak-to-peak into 75 ohms* |
| *Gain Adjustment Ragne* | *±6 dB (continuously variable)* |

Table 6B. Video Clamp Technical Characteristics.

**15 kHz Audio Demodulator - Part No. 141461**

General. *The audio demodulator unit (Photo No. 6214) is a plug-in module intended for operation with Scientific-Atlanta Series 400 Receiver Equipment. The input is composite baseband with audio subcarrier. The unit demodulates the nominal 6 MHz program subcarrier and provides a 15 kHz wide program sound output.*




15 KHz Audio Demodulator, Photo No. 6214

| Characteristics | Specification |
|---|---|
| *Input* | |
| *Subcarrier Frequency* | *5.8, 6.2, 6.8 MHz** |
| *Level* | *30 mV rms* |
| *Impedance* | *75 ohms* |
| *Program Output* | |
| *Frequency Range* | *50 Hz to 15 kHz* |
| *Frequency Response* | *±0.2 dB, 50 Hz to 15 kHz* |
| | *20-500 kHz frequencies at the program output will be 40 dB below the 50 Hz frequency* |
| *Impedance* | *600 ohms isolated or balanced* |
| *Return Loss* | *>26 dB* |
| *Level* | *+5 dBm nominal adjustable ±5 dB* |

*Scientific-Atlanta is now developing 6.6 MHz subcarrier units for INTELSAT service.

Table 7B. 15 kHz Audio Demodulator Technical Characteristics.

**Construction.** *Most of the components of the audio demodulator are located on two boards, the subcarrier board (A1) and the audio board (A2). Operating controls are on the front panel and the interface connector is on the rear of the module. Figure 10B shows the relationship of the circuits in the audio demodulator.*

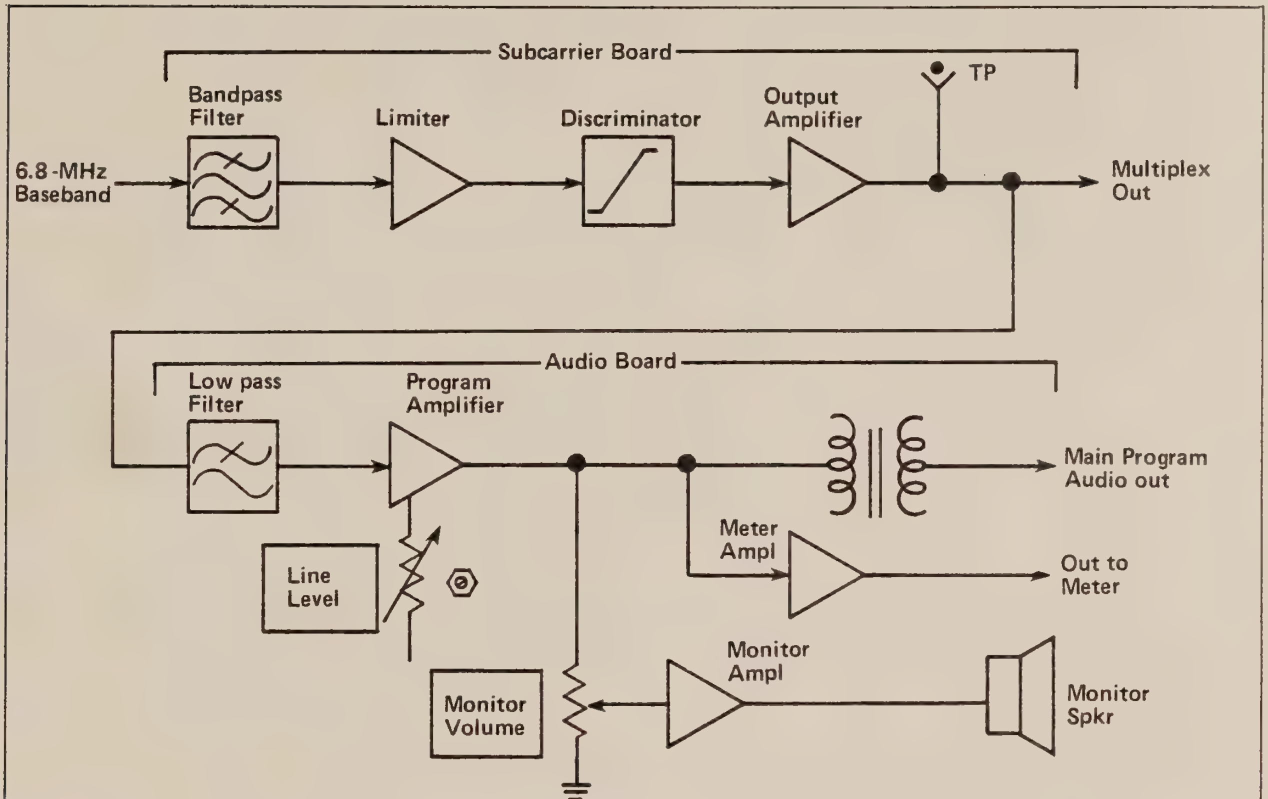



Figure 9B. Audio Demodulator Simplified Block Diagram.

BIBLIOGRAPHY

1. *Rhodes, Charles W. "Measuring Distortions in the Television Signal", Tektronix Application Note.*
2. *Schmid, Hans "Measurement of Television Picture Impairments Caused by Linear Distortions", Journal of the SMPTE, Vol: 77, March, 1968.*
3. *Schwartz, Mischa "Information Transmission Modulation and Noise", McGraw Hill, 1959.*
4. *"Transmission Distortions", Hewlett-Packard Application Note, July, 1973.*
5. *Weaver, L.E. "Television Video Transmission Measurements", Marconi Instruments, February, 1972.*

# VIDEO EXCITER PERFORMANCE
# and
# DESIGN CONSIDERATIONS

Written By:
Heinz Wegener
Revised & Edited By:
Edward J. Chapman
Manager, GCE Enginering
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## VIDEO EXCITER PERFORMANCE and DESIGN CONSIDERATIONS

**Introduction** *The heart of a video transmit system is the video exciter. The following is a summary of the purpose of the video exciter, definitions, and performance impact of critical specifications and a discussion of Scientific-Atlanta's 461 Exciter.*

**The Purpose of the Video Exciter** *The video exciter processes the video and audio signal, modulates a carrier with these signals, and finally converts the modulated carrier to the 5.9 to 6.4 GHz transmit band. Figure 1 is a block diagram of a video exciter.*

**Audio Path** *The audio signal is first lowpass filtered to remove unwanted high frequency components and is then pre-emphasized. Pre-emphasis is simply shaping the frequency response of the audio signal to accentuate the high frequency components relative to the low frequency components. Emphasis is used to improve the signal-to-noise ratio in an FM system by compensating for the triangular noise which occurs during FM demodulation. The signal is then injected into the subcarrier modulator whose output is a frequency modulated carrier centered at the subcarrier frequency. This subcarrier can now be summed in with the video signal.*

**Video Path** *The video signal may first pass through a lowpass filter although usually the video signal is fairly clean before it is injected into the exciter. The video signal is then pre-emphasized (to improve the signal-to-noise ratio after demodulation as well as reduce chrominance-to-luminance distortion) and is then ready for injection into the summing network. Also going into the summing network is a triangular waveform called the energy dispersal waveform. The inflection points of the energy dispersal waveform must be synchronized with the vertical blanking interval and this is accomplished with the dispersal synchronization network. The dispersal waveform causes the RF carrier to be modulated typically 1.0 MHz peak-to-peak with video and 2.0 MHz peak-to-peak when video is removed. The deviation caused by the dispersal waveform insures that the radiated power from the satellite is less than a certain maximum allowable level to minimize the possibility of interference with terrestrial microwave and in some cases adjacent satellites and to reduce intermodulation in half-transponder video transmission.*

**IF to RF Path** *The processed video signal, the modulated audio subcarrier, and the dispersal waveform are all summed together and then injected into the modulator. The output of the modulator is an IF carrier which has been frequency modulated by the composite signal out of the summing network. The IF signal is then bandpass filtered to remove undersired out-of-band components and injected into the upconverter. The upconverter provides the desired frequency selection and its output is in the 5.9 to 6.4 GHz band.*

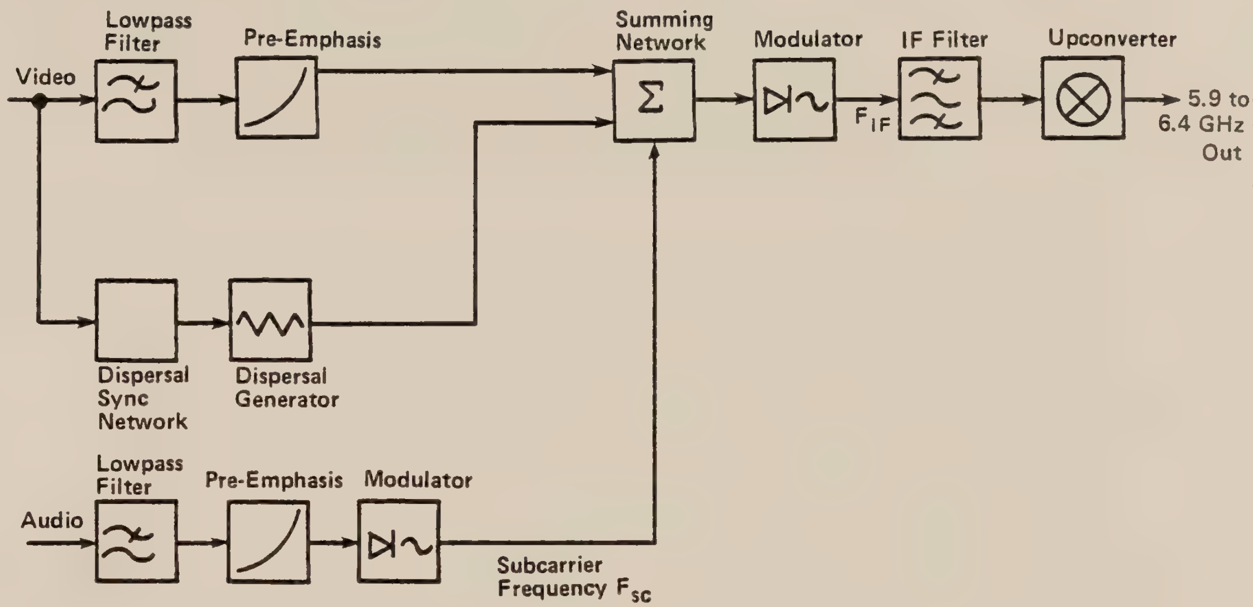


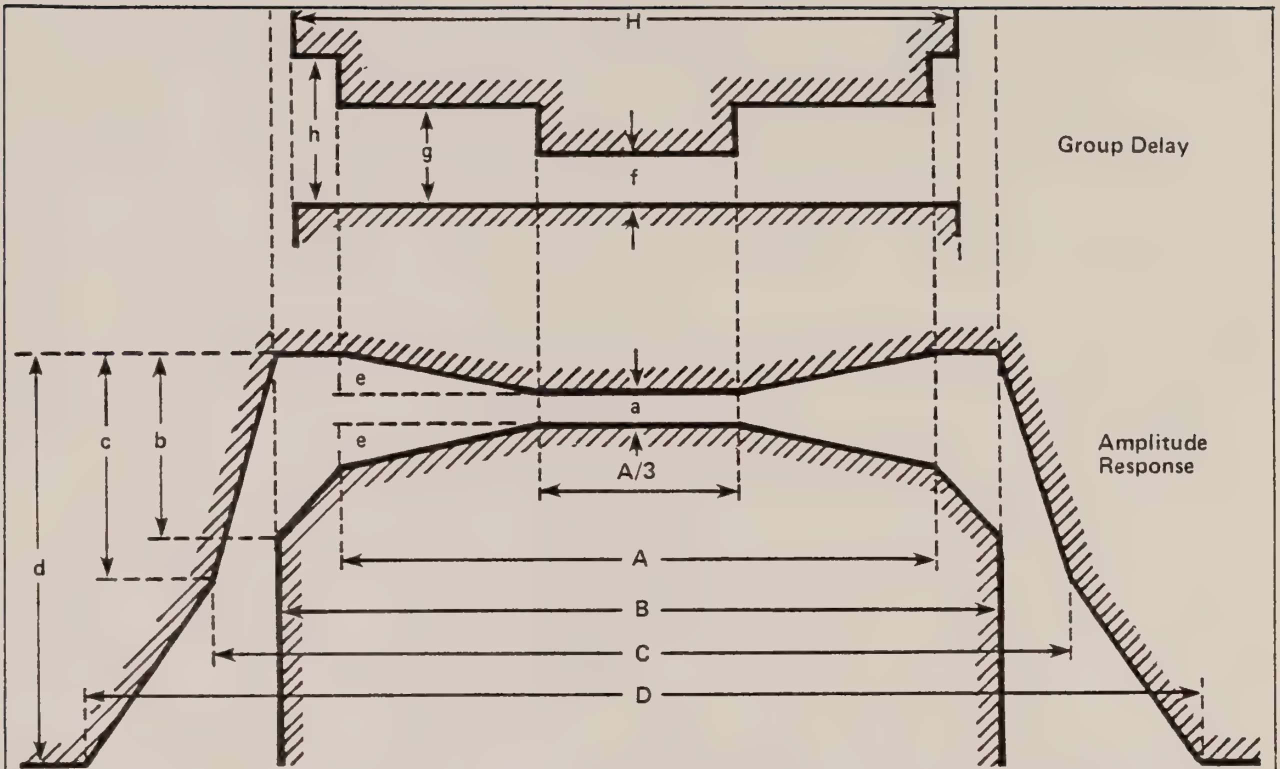

Figure 1. Video Exciter Block Diagram

**Exciter Specifications and Performance Criteria**

*When evaluating video exciters, it is important to understand the meaning and importance of various specifications and how they relate to performance degradations. Following is a discussion of various specifications.*

**RF and IF Gain Flatness**

*Although this is an FM system and prior to demodulation there is usually some form of amplitude limiting, severe amplitude non-flatness can cause AM to FM conversions to occur in the limiters which leads to intermodulation of the video signal. Intelsat document BG 28-72E provides frequency response tolerances which should be met in video exciters to minimize distortions due to gain flatness at RF and IF. Figure 2 is a reproduction of the 36 MHz mask. All Scientific-Atlanta exciters meet this mask requirement.*




| | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131630 | *36.0* | *28.8* | *36.0* | *45.25* | *60.0* | *0.6* | *2.5* | *10.0* | *25* | *0.3* | *33.1* | *3* | *5* | *15* |

**Figure 2. Exciter Amplitude Delay Characteristics**

**Phase Linearity - RF and IF** *Phase linearity is commonly discussed in terms of group delay which is defined as the derivative of the phase/frequency response. The group delay limits of the video exciter should meet the requirements of the mask of Figure 2. Non-linear phase results from conventional filtering and must be equalized to provide a group delay characteristic which falls within the mask of Figure 2 to yield satisfactory performance. Group delay distortions cause the following degradations of the demodulated signal.*

1. *Baseband gain/frequency variations.*
2. *Harmonic distortion which produces luminance/chrominance crosstalk.*
3. *Baseband intermodulation which causes unwanted frequency products to occur in the video signal.*
4. *Differential phase distortions.*

**Modulator Linearity** *Modulator linearity is a measure of the accuracy of the transfer function of the modulator (MHz of deviation/volt of input signal) over its deviation range. For good performance this accuracy (linearity) should be within 1% on any portion of the deviation range. Modulator nonlinearity causes harmonic distortion and excessive differential gain.*

**RF Return Loss**

*Poor return loss can result in group delay ripples which will lead to the same distortions mentioned in the phase linearity section. A return loss of at least 20 dB (VSWR@1.22:1) should be maintained at the RF output of the exciter as well as any other RF ports.*

**Video Specifications**

*Video specifications are fairly well outlined by the EIA, CCIR, and CCITT. Exciters which meet these recommendations will provide excellent video quality.*

**Audio Specifications**

*The main indicators of audio performance are audio gain/frequency response and harmonic distortion. Typical good performance numbers are ± .5 dB 50 Hz to 15 kHz gain/frequency response and less than 1% harmonic distortion.*

**Scientific-Atlanta Series 461 Video Exciter**

*Scientific-Atlanta's Series 461 Video Exciters are integrated modulator/upconverter units. Baseband and modulator sections are designed as plug-in modules; the dual-conversion upconverter is mounted to the chassis. This fully-interchangeable plug-in modular construction results in simplified maintenance and repair, and built-in monitoring and test facilities permit rapid status evaluations. Photograph 8345 shows a typical Series 461 Video Exciter equipped with transmit alarm, energy dispersal, modulator, and IF filter modules plus a switch-selectable frequency upconverter. An optional group delay module which houses up to 6 equalizer sections can be installed between the upconverter and IF filter if required.*

*The Series 461 Dual-Conversion Upconverter section is designed for use in wideband communications systems to convert an intermediate frequency of 70 MHz to any fixed carrier frequency within the 5925 to 6425 MHz frequency band. Carrier frequency selection is made by means of the second local oscillator only, with all filters remaining fixed-tuned. A 70 MHz IF amplifier precedes the first upconversion and provides automatic leveling of the RF output. A control is provided to set the operating RF output level.*

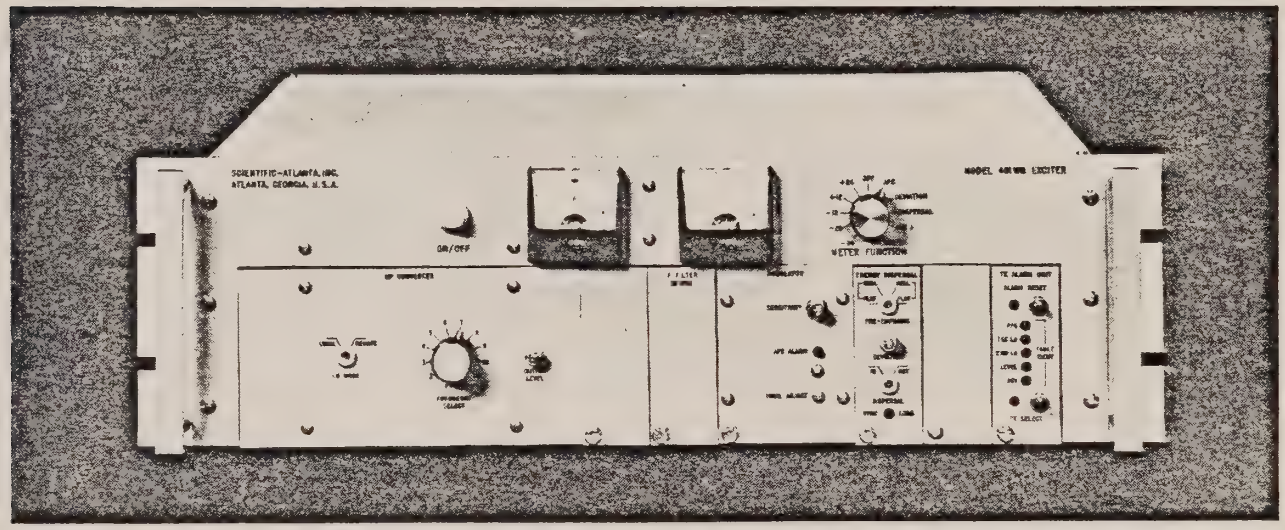
*Series 461 Dual-Conversion Upconverter section is designed for use in wideband communications systems to convert an intermediate frequency of 70 MHz to any fixed carrier frequency within the 5925 to 6425 MHz frequency band. Carrier frequency selection is made by means of the second local oscillator only, with all filters remaining fixed-tuned. A 70 MHz IF amplifier precedes the first upconversion and provides automatic leveling of the RF output. A control is provided to set the operating RF output level.*

*Features of the upconverter include:*

- *Selectable frequency to permit change of carrier frequency by changing the frequency of second local oscillator only.*
- *10 dB output level adjustment range.*
- *Solid-state reliability with modular construction.*
- *Remote frequency selection or synthesizer input available, as option.*
- *Internal synthesizer available, as option.*

*The upconverter is packaged in a single 5-1/4inches high x 19 inches wide chassis which is designed for standard rack mounting. Seven plug-in module slots are available in the upconverter chassis. These slots are used to accommodate energy dispersal, baseband processing, modulator, IF filter, equalizer, and alarm modules when the upconverter is used as part of a complete baseband RF-transmitter exciter. Subcarrier and cue modulators are housed in a separate program/cue auxilliary mainframe which is also a 5-1/4-inch high x 19-inch wide chassis.*

*The wideband modulator is designed for use with either video or message exciters in satellite communications earth stations. Modulator design consists of a series of plug-in modules which are installed in the blank mainframe space provided with the upconverter. Each modulation section consists of a baseband unit providing pre-emphasis, in the energy dispersal unit, an FM transmitter, and an IF filter. Options such as transmit alarms and baseband combiners are also available. (The alarm unit is required in each exciter for redundant systems as an input to the protection-switching logic).*




Series 461 Video Exciter

*A block diagram of the Series 461 is shown in Figure 3.*

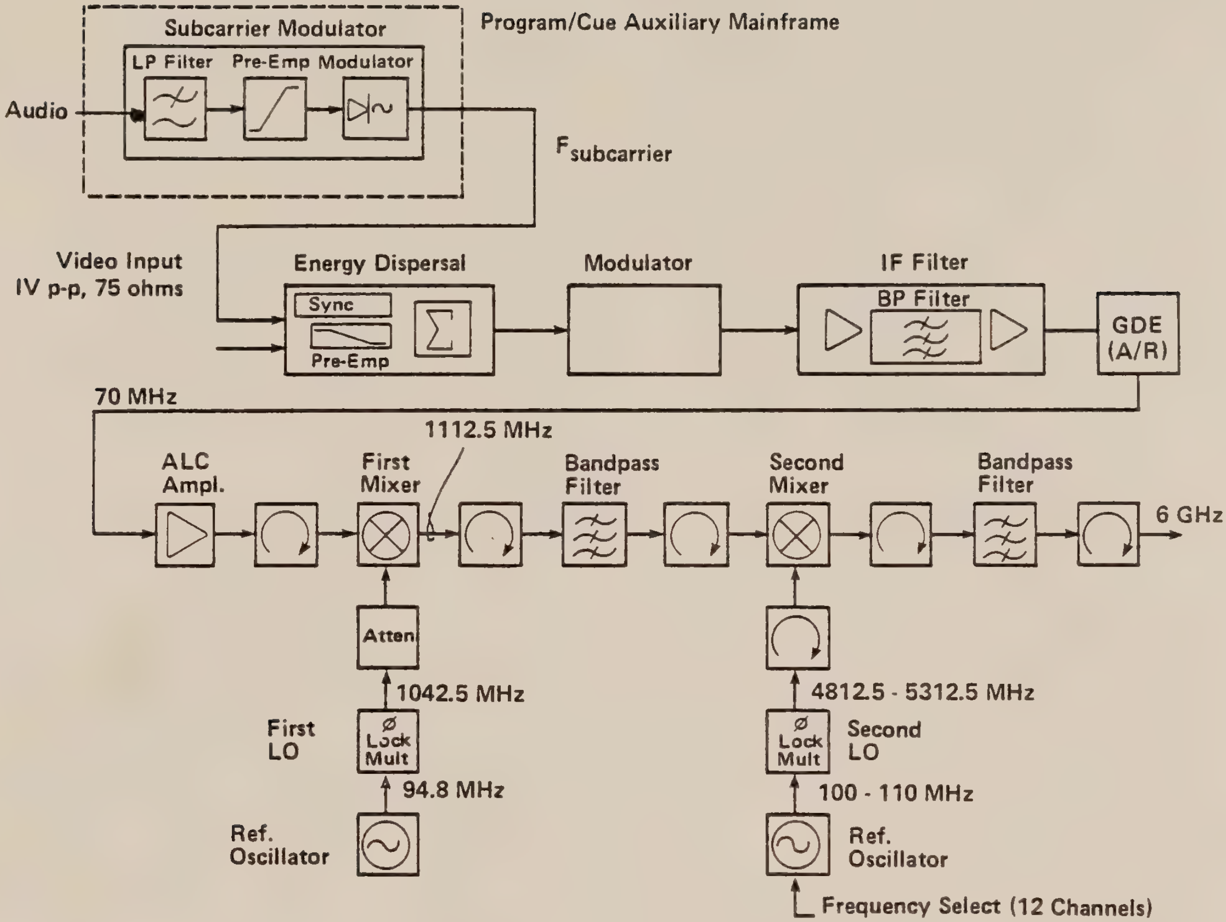



**Figure 3. Dual-Conversion Video Exciter Block Diagram - Series 461**

*The audio signal is injected into the subcarrier modulator where it is lowpass filtered and pre-emphasized. The subcarrier is then modulated by the processed audio signal and injected into the video energy dispersal unit (EDU). Plug-in boards internal to the subcarrier modulator allow processing the audio with various lowpass filters and pre-emphasis networks. The subcarrier modulator is physically located in an auxilliary mainframe which has its own power supply and can accept 3 additional audio modules (cue modulators, program demodulators, and cue demodulators).*

*The video signal is injected into the video energy dispersal unit where it is pre-emphasized. The triangular energy dispersal waveform is generated in this module. The video, audio subcarrier, and the energy dispersal waveform are summed together and amplified in the energy dispersal unit to the proper level for injection into the modulator.*

*The modulator provides a 70 MHz carrier which is modulated with the composite signal from the video EDU. Modulation is accomplished at a center frequency of 1112.5 MHz which provides excellent linearity and group delay characteristics across the maximum modulation bandwidth. The modulated signal is then downconverted to the 70 MHz IF frequency.*

*Following the modulator is the IF filter which provides rejection of out-of-band frequencies. The filters used are identical to the filters in the receiver and are all internally delay equalized.*

*The IF signal next goes into the dual conversion upconverter. The upconverter first converts the 70 MHz IF frequency to 1112.5 MHz. Final frequency selection is accomplished by simply providing the proper second local oscillator frequency from the 4.8 to 5.3 GHz source. This is the same source used in the receiver and the reference frequency is in the 100 to 110 MHz range. The crystal oscillators used as the reference frequency are the same in the exciter as the receiver for the same transponder.*

**461 Checkout Plan** *All modules are individually checked out before they are put into the receiver. The entire receiver is then burned in for approximately 1-2 weeks to reduce the probability of "infant" mortalities. After this burn in period, receiver tests are run to check gain, gain/frequency response, group delay, and all video tests.*

**461 Maintenance Requirements** *The only required maintenance on the 461 exciter is periodic video and audio output level checks.*

Frequency Range
*5925 to 6425 MHz*
Level
*-10 dBm to -20 dBm*
Level Stability
*±0.25 dB/day*
Impedance
*50 ohms*
Return Loss
*20 dB minimum*
Frequency
*Dual conversion with switch-selectable crystal oscillators and manually tuned second local oscillator. Optional synthesizer.*
Local Oscillator Stability
*1 part in $10^6$/day*
*2 part in $10^7$/°C (0 to 50°C)*
IF to RF Amplitude Response
*0.25 dB, $f_o$ ±18 MHz*
Modulator Linearity
*1%, $f_o$ ±18 MHz*
Operating Parameters
Video Deviation Range
*5 to 12 MHz peak at pre-emphasis crossover frequency*
IF Bandwidths
*17.5 to 36.0 MHz*

Video Input
Frequency Response (BB-RF)
*15 Hz to 12 kHz, ±0.5 dB*
*12 kHz to $f_v$ maximum, ±0.25 dB*
Level
*1.0 volt p-p, ±3 dB adjustment*
Impedance
*75 ohms, unbalanced*
Return Loss
*26 dB*
Video Distortion Characteristics
Differential Phase (10 to 90% APL)
*±0.5°*
Differential Gain (10 to 90% APL)
*±2.0%*
Line Time Waveform Distortion
*Less than 0.5% tilt*
Field Time Waveform Distortion
*Less than 1.0% tilt*
Audio
Frequency Response
*50 Hz to $F_{max}$ ±0.5 dB*
Harmonic Distortion
*≤ 1%*

Series 461 Video Exciter Characteristics.

## APPENDIX A Video Exciter Module Description

**Exciter Mainframes** *The mainframes are standard 19-inch rack mounted designs that are 5.25 inches high. The mainframe is a U-shaped aluminum chassis with an integral rear panel that contains all input/output connections. All operating controls are located on the front panel.*

*DC operating voltages are carried to the interface connectors of all modules, whether or not a module is inserted. Signal input and output interconnections are made via the rear panel (see Photo No. 8489) connectors so that, with the appropriate external patch cables connected, the modules in any configuration will be properly interconnected. Rear-panel patches are also furnished for such signals as the 70 MHz IF and 1st local oscillator to permit access to these signals for system testing and/or calibration.*

*Signal flow through the exciter is quite straightforward and is illustrated by the functional block diagram of the mainframe (Figure 1A).*

*The left hand section of the unit contains the local oscillator for the modulator. The right section of the mainframe provides slide-in mounting facilities for the IF and baseband processing modules. Machined tracks in a plate at the bottom of the chassis guide the modules smoothly into position so they will positively mate with interface connectors on a bracket near the rear of the chassis. One important feature of Scientific-Atlanta's GCE is that the second slot from the right, with the mainframe viewed from the front, can be used as a test slot. The pins of the interface connector on the module plugged into the test slot are brought out to the rear of the chassis. In this way, the power supply can be used to power the module while it is under test. The unit may or may not be operational, however, under these conditions.*

*The Model 402A Power Supply is a plug-in unit intended to furnish dc power to modules of the Scientific-Atlanta Series 400 equipment. Four voltages are produced: +24V dc, +12V dc, -24V dc, and -12V dc. Current limiting is furnished for all four supplies; overvoltage protection in the form of a crowbar circuit is provided on the 12-volt supplies.*

*Ripple and noise on the output of the supplies is typically less than 10 mV peak-to-peak for the 24 volt supplies, and 5 mV peak-to-peak for the 12-volt supplies. Total load and line regulation for all supplies is typically less than 0.5%. This unit mounts on the rear apron of each chassis.*

*With regard to controls/metering of the mainframe, the units have a multifunction meter with associated function switch. The following tabulations provide the characteristics of the controls and metering.*

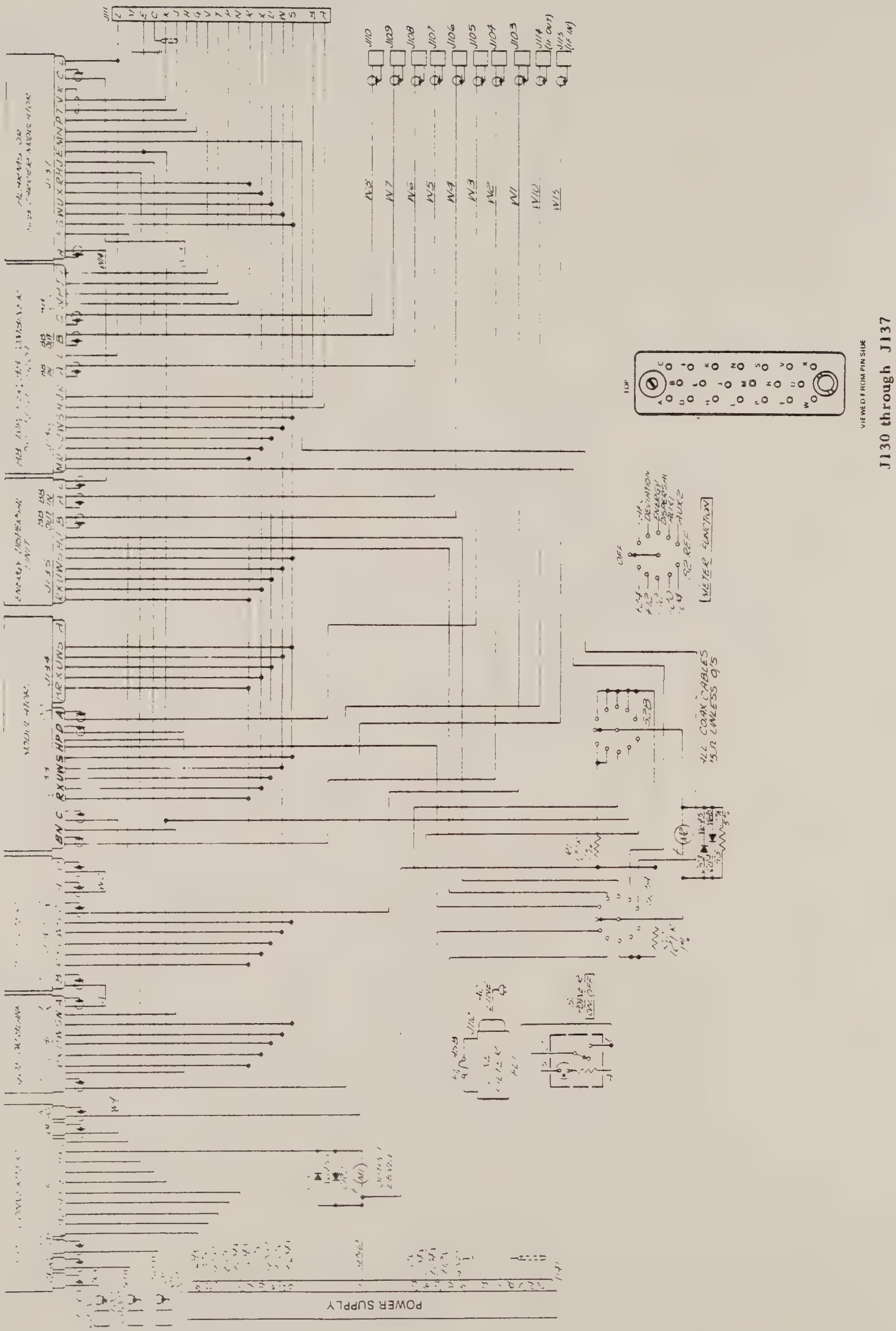
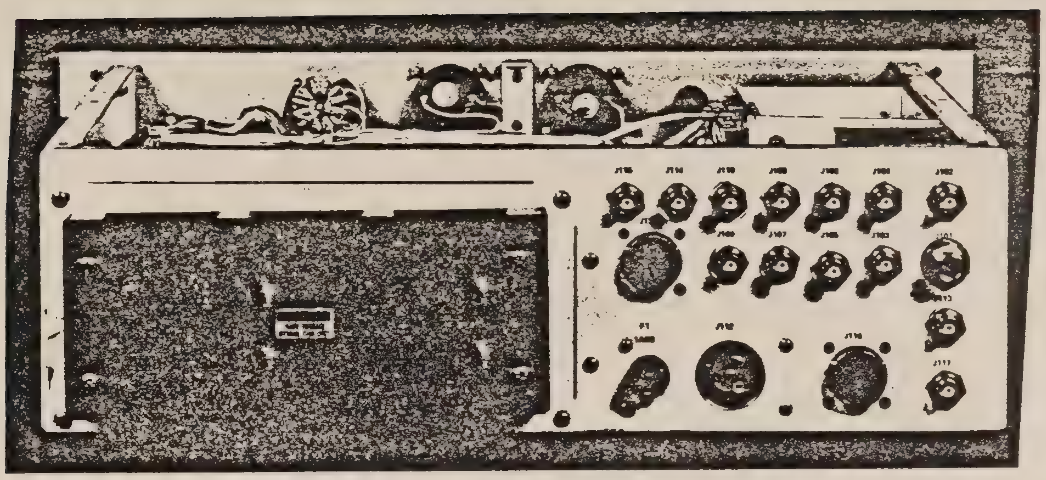



Figure 1A. Series 461WB Exciter Mainframe



Model 461 WB Rear Panel

### Exciter Mainframe Controls and Indicators

| Control/Indicator | Position | Function |
|---|---|---|
| Meter Function Switch | OFF | Meter disconnected |
| | -24 | Meter reads voltage on exciter -24V dc bus |
| | -20 | Meter reads output from -20V dc supply in upconverter (derived from exciter -24V dc bus) |
| NOTE Read voltages on top meter scale | -12 | Meter reads voltage on exciter -12V dc bus |
| | +12 | Meter reads voltage on exciter +12V dc bus |
| | +24 | Meter reads voltage on exciter +24V dc bus |
| | AFC<br>Deviation<br>Dispersal<br>AUX 1<br>AUX 2 | These switch positions connect the meter to read various baseband and other levels at the inputs and outputs of the modules plugged into the mainframe |

**Frequency Upconverters** *The frequency upconverter utilized in the exciters is Scientific-Atlanta's Standard Model 461WB(D) 5.9 - 6.4. This unit bolts into the extreme left hand side of the mainframe. Power and interconnections to the rear apron terminals are made in the mainframe.*

*The frequency upconverters utilized in Scientific-Atlanta's Series 461 Exciters are dual conversion units that have an output frequency in the 5.925 - 6.425 MHz band. The input frequency is an IF signal in the 52 - 88 MHz range. The standard model has 12 switch-selectable output frequencies and as options the particular frequency can be remotely selectable or can be synthesizer controlled. The upconverter plugs into the left hand position at the mainframe and all interconnections, signal and power are made inside the mainframe. The local oscillation signal is also cabled to the mainframe rear apron where it is patched back into the unit for normal operation or can be made available for other functions.*

*The function of the upconverter is to convert the incoming 70 MHz IF signal to the desired transmit RF channel frequency. This is accomplished in two frequency conversions. The first conversion is to an IF of 1112.5 MHz. At this IF, signals are filtered and then further converted to 5.925 - 6.425 GHz. Figure 2A is the upconverter block diagram.*

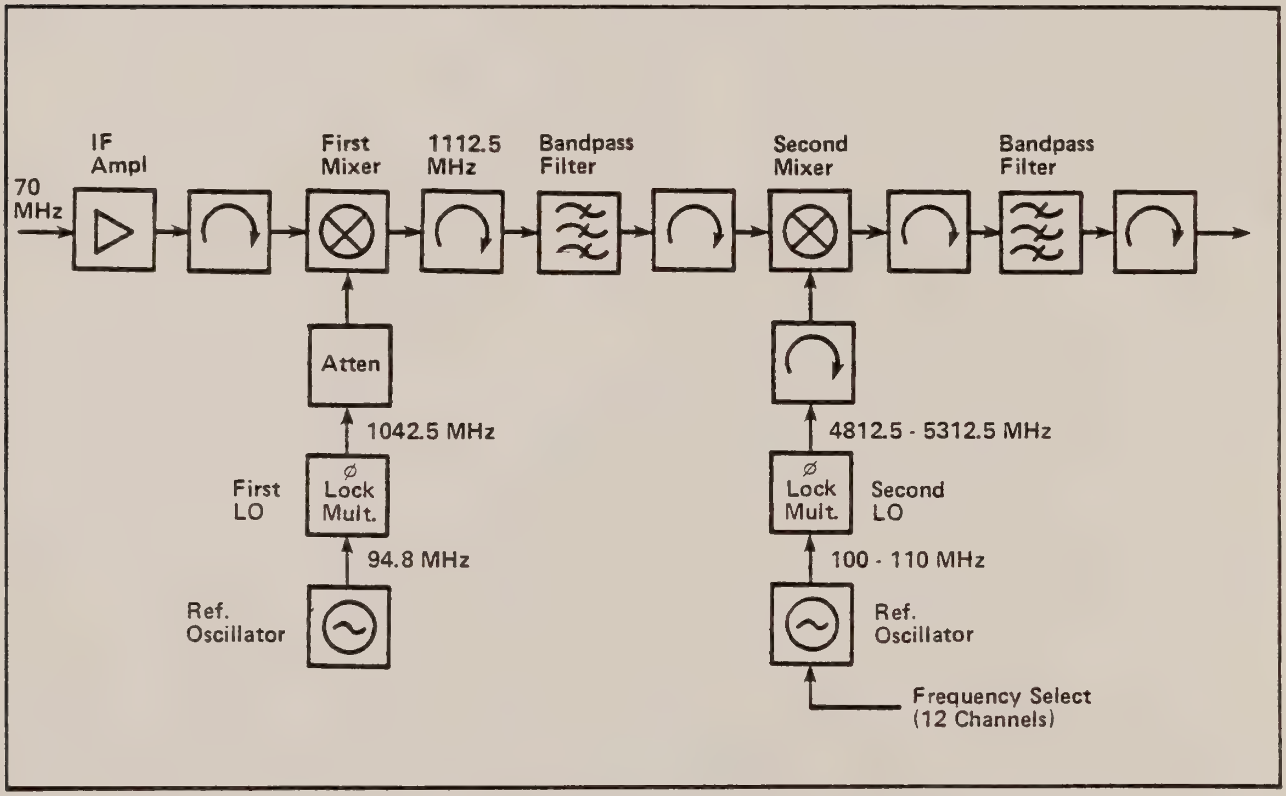
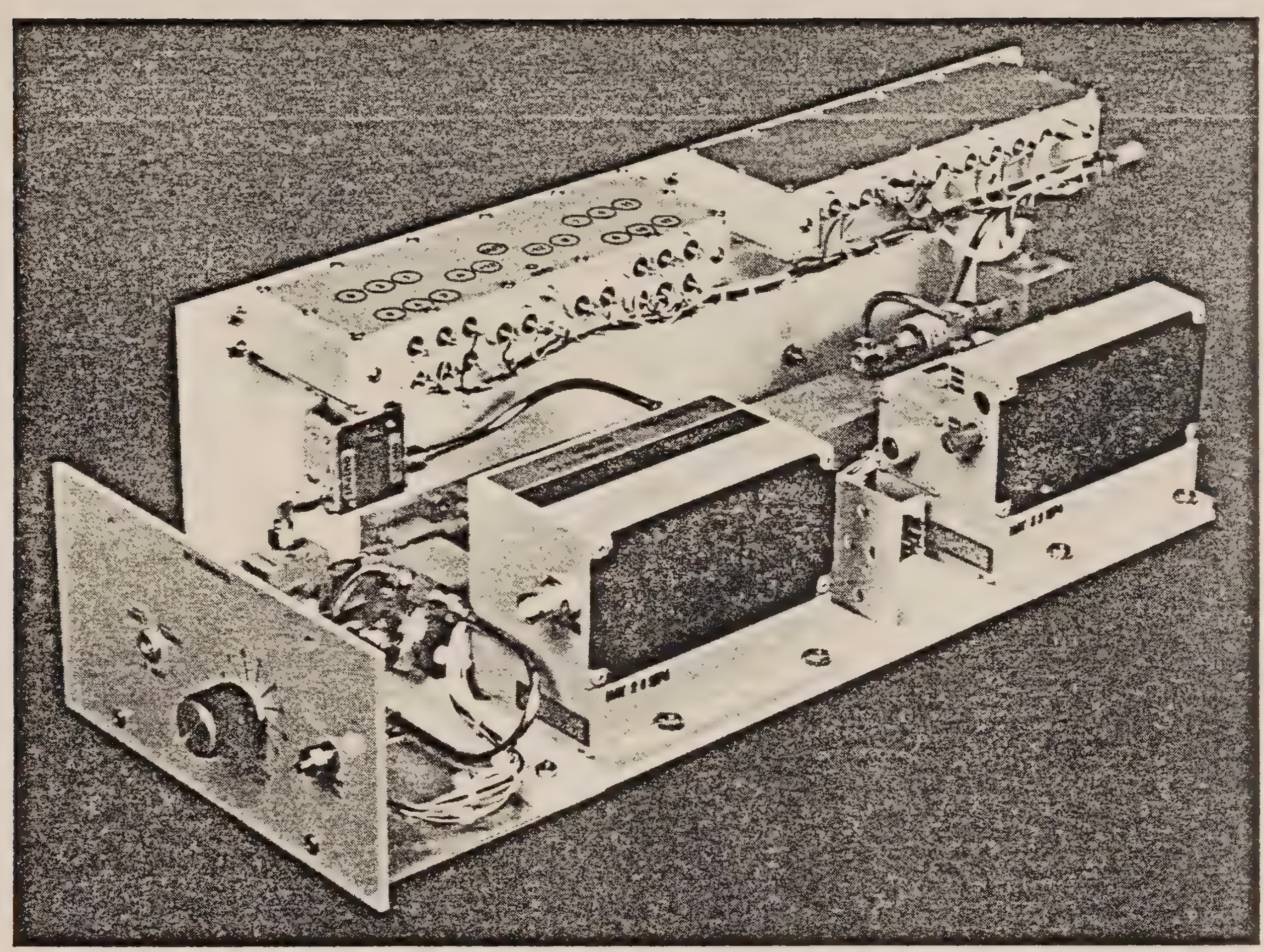



Figure 2A. Block Diagram Series 461 Dual Conversion Upconverter

*Signals entering the upconverter first pass through an input amplifier, a three stage amplifier that amplifies the IF signal to a maximum level of +7 dBm (nominal). It contains an internal AGC loop that is controlled by the external level-setting potentiometer. The AGC loop provides automatic leveling (ALC) of the upconverter IF output. The level-setting potentiometer allows varying the output of the IF amplifier and hence the upconverter output over a range in excess of 10 dB.*



Model 461WB(D) 5.9 - 6.4 Upconverter Module

*The output of the IF amplifier is fed to a mixer, which upconverts the 70 MHz IF signal to the first IF of 1112.5 MHz. The mixer local oscillator for this conversion is accomplished by a phase-locked multiplier source operating at a fixed frequency of 1042.5 MHz. The output of the phase-locked source is attenuated by approximately 12 dB of attenuation to result in a LO drive level between +12 and +15 dBm at the LO port of the mixer. The IF output at 1112.5 MHz is then fed to a filter. The filter is equipped with input and output isolators to provide low VSWR terminations for the filter. The function of this filter is to provide attenuation of the first conversion image, other mixer spurious products, and the 1042.5 MHz local oscillator signal. After filtering, the signal is fed to the IF port of a second mixer which upconverts the 1112.5 MHz IF signal to an output frequency in the 5925 to 6425 MHz range. Upconverters equipped with the power output option have an amplifier inserted between the filter and the IF port of the mixer to provide approximately 10 dB of IF amplification prior to the final conversion. The output frequency of the final conversion is determined by the frequency of its local oscillator which is supplied by phase-locked multiplier. This oscillator operates in the 4812.5 to 5312.5 MHz range and provides a net reference frequency multiplication of X48. The reference frequency for this multiplication may be obtained from an*

*internal crystal oscillator, from an external signal generator or synthesizer, or optionally from an internal synthesizer. The reference frequency lies in the 100 to 110 MHz range. The reference oscillator frequency for a given output frequency is determined by the following relationship:*

$$f_{ref} = \frac{f_{tx} - 1112.5}{48}$$

*After conversion to the final output frequency, the RF signal is passed through a bandpass filter. This filter provides attenuation of the final conversion image frequency and attenuation of the local oscillator frequency fed through mixer. It also provides attenuation of out-of-band spurious mixing products.*

*The upconverter includes an integral -20 volt regulator to operate the phase-lock sources. This regulation is accomplished by transistor regulator Q1 referenced to the Zener diode CR2 and diode CR1.*

*The upconverter controls are located on the front panel and are:*

*Frequency Select*

*Selects the frequency to be transmitted. In the standard upconverter, the switch positions are marked 1 through 12.*

*LO Mode*

*During normal operation, this switch is left in the Local position, and the frequency of the 1st LO is determined by the front panel Frequency Select switch. In the Remote position, 1st LO frequency is determined by an external source, external switch, or internal synthesizer.*

## Upconverter Technical Characteristics

**Input**
Frequency
*70 MHz ±20 MHz*
Level (without IF filter)
Nominal
*-10 dBm*
Maximum
*-5*
Minimum
*-20*
Level (with IF filter)
Nominal
*-18 dBm*
Maximum
*-13 dBm*
Minimum
*-28 dBm*
Impedance
*75 ohms unbalanced*
Return Loss
*26 dB over IF bandwidth*
Bandwidth
*40 MHz*

**Output**
Frequency
*5925 to 6425 MHz*
Level
Standard
*-10 dBm to -20 dBm*
Optional
*0 dBm to -10 dBm*
Level Stability
*±0.25 dB/day, 25 °C*
Impedance
*50 ohms*
Return Loss
*20 dB minimum*

**IF to RF**
Gain Response
*±0.25 dB, $f_o$ ±18 MHz*
Delay Distortion
Linear
*0.03 ns/MHz, $f_o$ ±18 MHz*
Parabolic
*0.01 ns/MHz$^2$, $f_o$ ±18 MHz*

**Intermodulation (Output Intercept Point)**
Standard
*-3 dBm*
Optional (With 0 dB output Power Option)
*+5 dBm*

**Spurious Outputs**
K
*<-100 dBm/4 kHz*

**Local Oscillator**
Standard
Frequencies
*12 switchable*
Stability
*1 part in $10^6$/day (25 °C)*
*2 parts in $10^7$/°C (0 - 50 °C)*
Optional
Frequencies
*1 to 12 as specified*
Stability
*±200 Hz/day (15 - 35 °C)*
Synthesizer
*5925 - 6425 MHz in 0.25 MHz steps*

**Weight**
*40 lbs*

**Power Consumption**
*105 - 125V ac, 47 - 63 Hz or*
*215 - 250V ac, 47 - 63 Hz, 150W*

**IF Filters** *The IF Filters (see Photo No. 6623) are front panel plug-in modules for operation with the Series 411 Receivers and Series 461 Exciters. These units plug into specific slot assignments of the mainframe and receivers operating power from the mainframe power supply. Connections are made to the filter through an interface connector on the rear of the module.*

*The purpose of the filter is to provide rejection of unwanted out-of-band signals and to provide amplification of the desired in-band signals. In addition, equalization of group delay due to the filter is provided. The following is a block diagram of the IF filter.*


Figure 3A. 'IF Filter Block Diagram

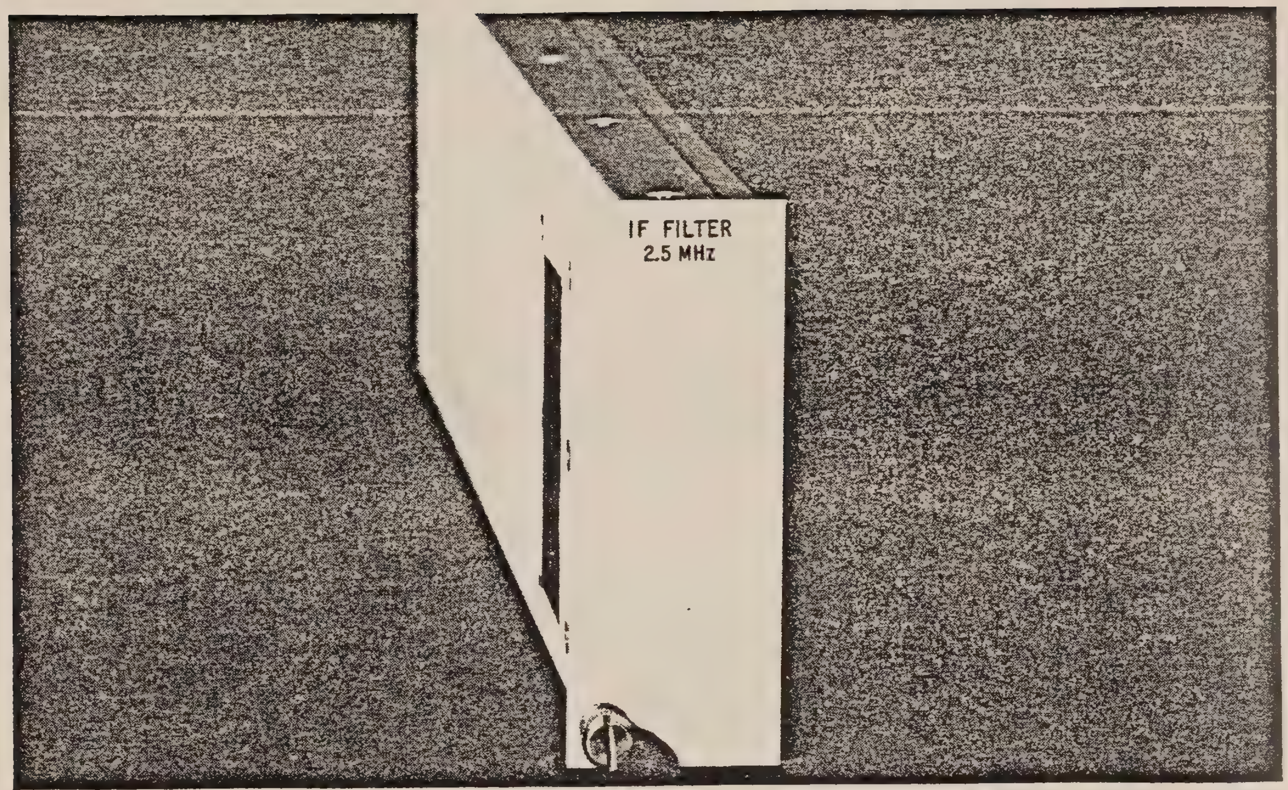
*The technical characteristics of the IF filters are listed in the following table:*

| BW (MHz) | Max Input Level | Receiver Gain | Exciter Gain |
|---|---|---|---|
| **Narrow Band Filters*** | | | |
| 2.5 | -24.6 dBm | 19.8 ±1 dB | 8 ±2 dB |
| 5.0 | -21.6 dBm | 16.6 ±1 dB | 8 ±2 dB |
| 7.5 | -19.8 dBm | 14.8 ±1 dB | 8 ±2 dB |
| 10 | -18.6 dBm | 13.6 ±1 dB | 8 ±2 dB |
| **Wideband Filters** | | | |
| 15.0 | -16.8 dBm | 11.8 ±1 dB | 8 ±2 dB |
| 17.5 | -16.1 dBm | 11.1 ±1 dB | 8 ±2 dB |
| 20.0 | -15.6 dBm | 10.6 ±1 dB | 8 ±2 dB |
| 25.0 | -14.6 dBm | 9.6 ±1 dB | 8 ±2 dB |
| 30.0 | -13.8 dBm | 8.8 ±1 dB | 8 ±2 dB |
| 36.0 | -13.0 dBm | 8.0 ±1 dB | 8 ±2 dB |

*1.25 MHz Bandwidth Filters are now being added.

Table 4A. IF Filter Characteristics

*IF filter amplitude and delay characters are shown in Figures 5B and 6B.*




IF Filter Module

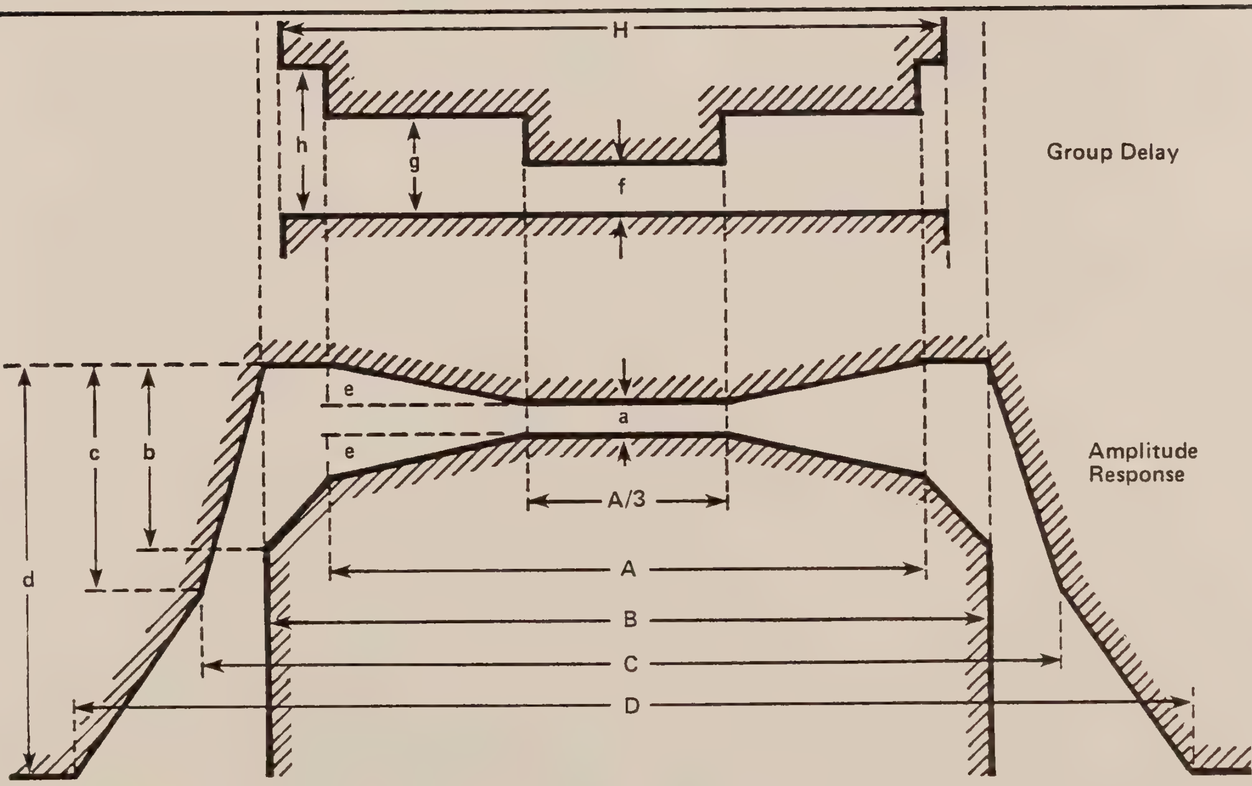



Figure 5A. IF Filter Amplitude-Delay Characteristics

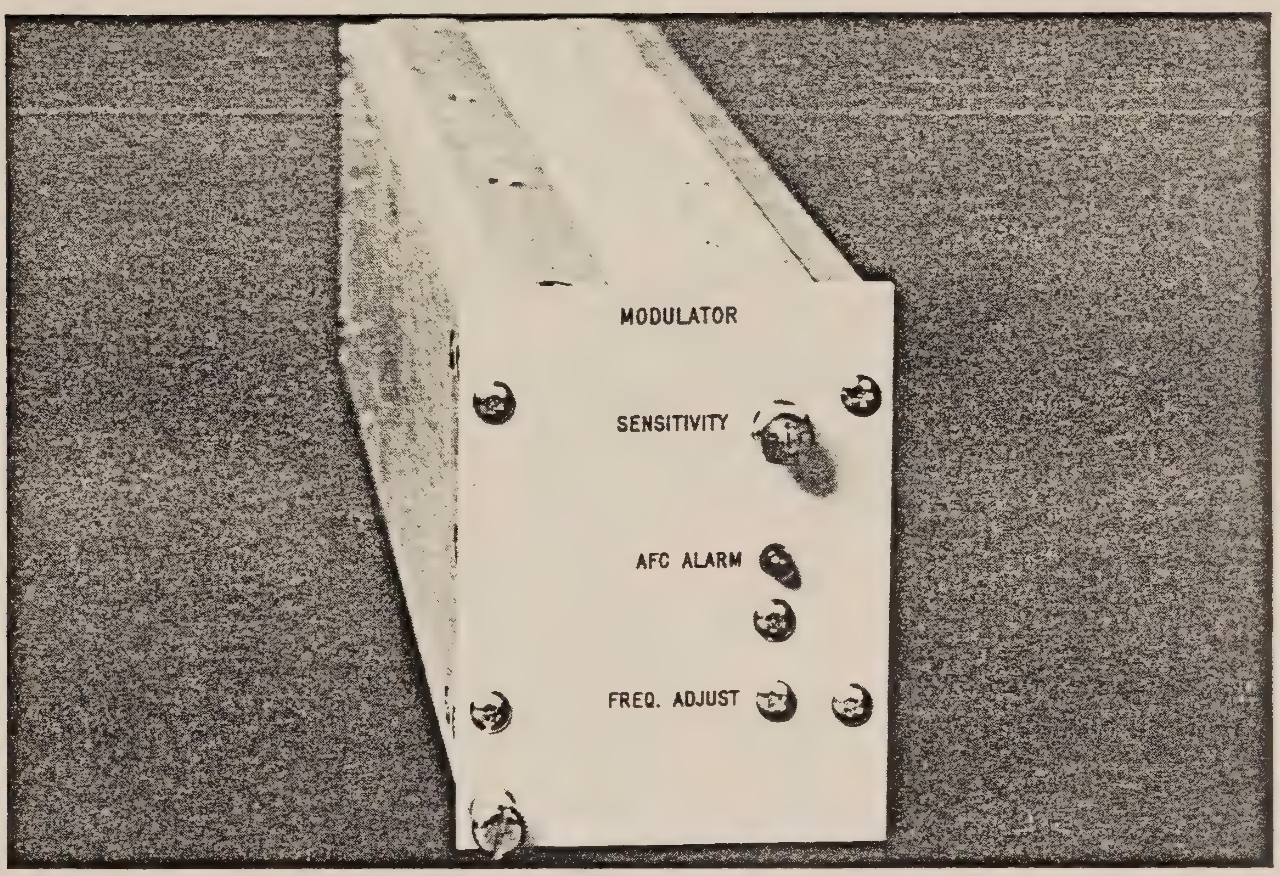
| S-A Part No | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131621 | *2.5* | *1.8* | *2.25* | *2.75* | *8.0* | *0.7* | *1.5* | *2.5* | *25* | *0* | *2.1* | *16* | *16* | *20* |
| 131622 | *5* | *3.6* | *4.5* | *5.25* | *13.0* | *0.5* | *2.0* | *3.0* | *25* | *0* | *4.1* | *12* | *12* | *20* |
| 131623 | *7.5* | *5.4* | *6.75* | *7.75* | *17.0* | *0.4* | *2.5* | *4.0* | *25* | *0* | *6.2* | *12* | *12* | *20* |
| 131624 | *10* | *7.2* | *9.0* | *10.25* | *19.0* | *0.3* | *2.5* | *5.0* | *25* | *0.1* | *8.3* | *9* | *9* | *18* |

| S-A Part No. | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131625 | *15* | *10.8* | *13.5* | *15.5* | *25.0* | *0.3* | *2.5* | *5.5* | *25* | *0.1* | *12.4* | *6* | *6* | *15* |
| 131626 | *17.5* | *12.6* | *15.75* | *18* | *26.5* | *0.3* | *2.5* | *6.5* | *25* | *0.1* | *14.2* | *6* | *6* | *15* |
| 131627 | *20* | *14.4* | *18.0* | *20.5* | *28.0* | *0.3* | *2.5* | *7.5* | *25* | *0.1* | *16.6* | *4* | *5* | *15* |
| 131628 | *25* | *18.0* | *22.5* | *25.75* | *34.0* | *0.3* | *2.5* | *8.0* | *25* | *0.2* | *20.7* | *3* | *5* | *15* |
| 131930 | *36.0* | *28.8* | *36.0* | *45.25* | *60.0* | *0.6* | *2.5* | *10.0* | *25* | *0.3* | *33.1* | *3* | *5* | *15* |
| 131929 | *30 (video)* | *24.0* | *30.0* | – | – | *0.5* | *2.5* | – | – | *0.3* | *30.0* | *5* | *5* | *15* |

**Figure 6A. IF Filter Amplitude-Delay Characteristics.**

**Modulator - Part No. 131725** *The modulator accepts processed baseband signals as an input and produces a modulated IF carrier centered at 70 MHz. The output level is compatible with the upconverter input level requirements. The modulators are capable of operating at any channel capacity between 24 and 1872 channels and with any video format.*

*The modulator accepts baseband signals as an input and produces a modulated IF output. It contains AFC circuitry to accurately control carrier center frequency and provides suitable status alarms and monitors. Referring to the block diagram, the baseband input signal is first buffered in a baseband amplifier. The amplifier contains gain adjustment facilities to set the deviation constant of the modulator. The baseband signal is ac coupled into a VCO operating at 1112.5 MHz. The ac coupling provides flat frequency response down to 20 Hz. The VCO is the deviation mechanism in the modulator. Operation at 1112.5 MHz provides extremely linear deviation as a function of baseband input level and is also a convenient frequency to use in that it can be mixed to 70 MHz by using an LO output from the upconverter first local oscillator. Following mixing to 70 MHz, the carrier is buffered and a sample is split out to operate the AFC circuitry. An additional output buffer amplifier is provided following the splitter to provide the final IF output. The AFC circuitry consists of a discriminator which alternately samples the modulator 70 MHz output and the output of a 70 MHz crystal oscillator. The alternate samples are stored in sample and hold circuits at the discriminator output and compared in a differential amplifier. The differential amplifier produces an AFC loop error signal which is direct coupled to the*




Frequency Modulator Transmitter

*VCO input through appropriate filtering. The loop operates to drive the VCO center frequency to 1112.5 MHz which produces 70 MHz at the modulator IF output. An AFC alarm detector is provided to detect excessive AFC errors. A sample of the baseband input just prior to application to the VCO is also provided on a buffered output. This output may be used to drive an optional baseband pilot continuity alarm. A block diagram of the Scientific-Atlanta modulator is shown in Figure 7A.*

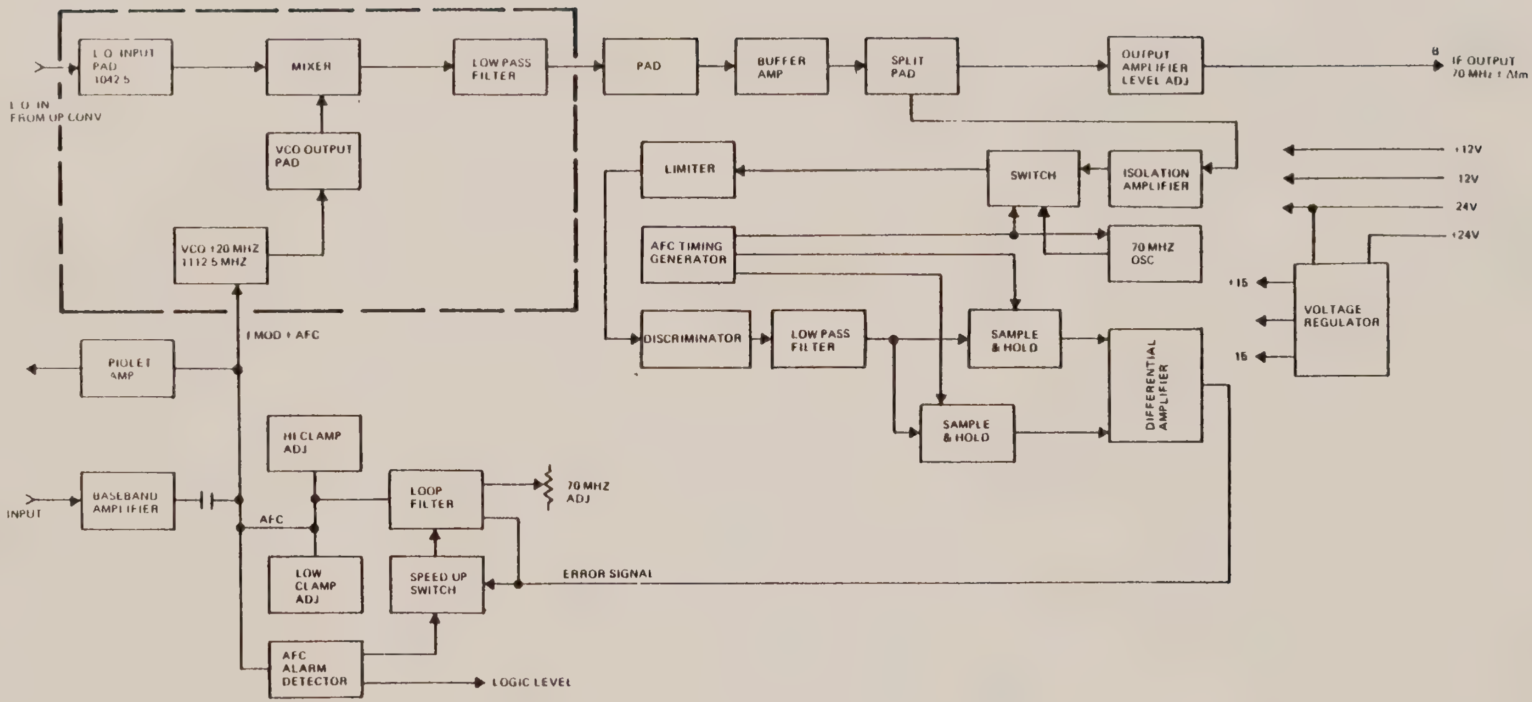



Figure 7A. Message Modulator Block Diagram

**Baseband Input Impedance**
*75 ohms, unbalanced*
**Baseband Return Loss**
*26 dB min (20 Hz to 8.3 MHz)*
**IF Output Impedance**
*75 ohms, unbalanced*
**IF Output Return Loss**
*26 dB min (52 - 88 MHz)*
**Channel Capacity**
*12 to 1872 channels and all deviations per BG28 72E*
**Video**
*All 525L and 625L formats*
**Frequency Response**
*±0.2 dB (20 Hz to 8.3 MHz)*
**IF Amplitude Response**
*±0.25 dB (52 MHz - 88 MHz)*
**Baseband Level Stability**
*±0.1 dB per day*
*±0.3 dB per month*
**IF Output Level**
*-18 dBm, nominal*

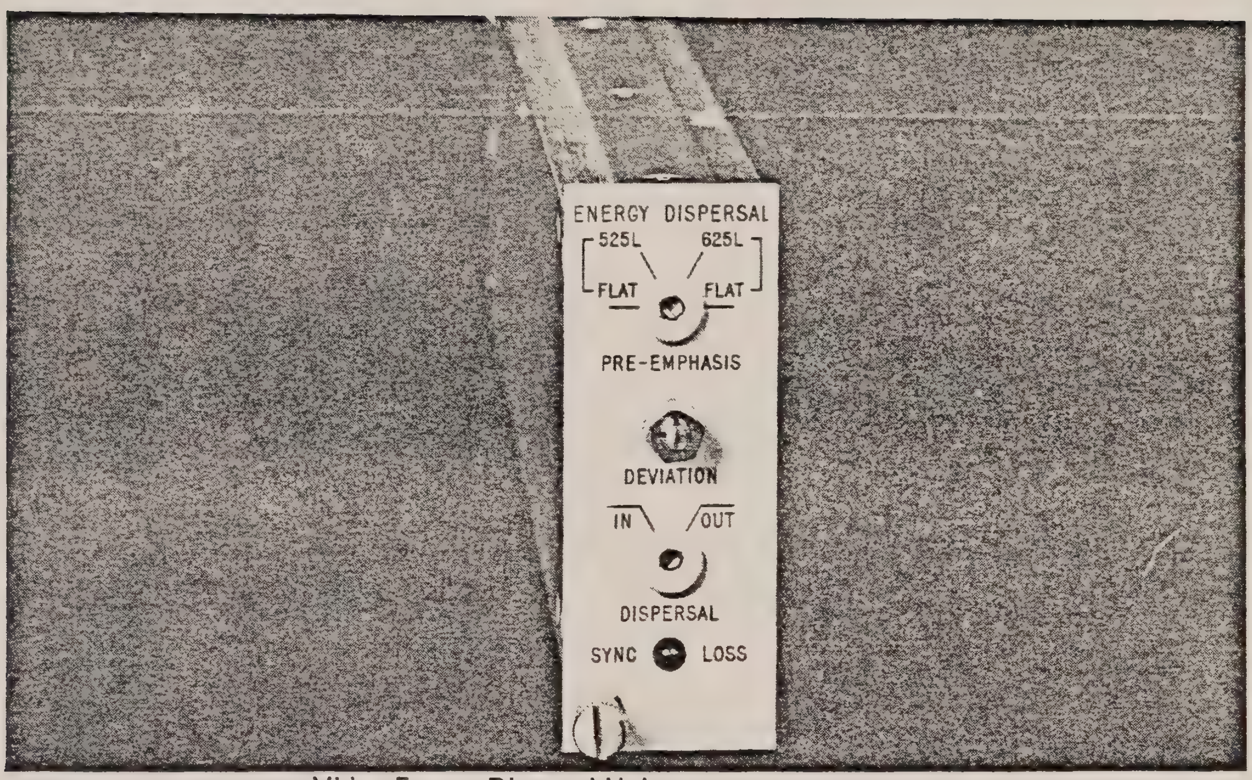
**IF Output Frequency Accuracy**
*±50 kHz (long term and temporary)*
**Linearity**
*Better than 1% over ±18 MHz*
**Group Delay, Total**
*Less than 0.1 n sec ±18 MHz*
Linear
*±0.2 n sec/MHz*
Parabolic
*0.05 n sec/MHz $^2$*
Ripple
*0.6 n sec peak-to-peak*
**Group Delay Variation**
Linear
*±0.02 n sec/MHz per month*
Parabolic
*0.005 n sec/MHz $^2$ per month*
**Intermodulation Distortion**
*53 dB min*
**Spurious Output**
*-100 dBm per 4 kHz*
**Alarm Indication**
*Loss of AFC lock*

## 525/625-Line Video Energy Dispersal Unit

**Description** *The video energy dispersal unit, part number 131728, is a plug in module intended for operation with the Scientific-Atlanta Series 461 Exciter equipment. Operating power is received from the mainframe of the exciter. The energy dispersal unit has three primary functions. It provides:*

*a. Pre-emphasis and baseband filtering for 525 and 625 line video signals via plug in boards.*
*b. Injection of the energy dispersal waveform.*
*c. The summing point for an audio subcarrier if one is required.*

**Circuit Description** *The purpose of the video energy dispersal unit is to inject a dispersal waveform of the proper amplitude and synchronization to meet the requirements of BG28 72E. In addition, this unit provides pre-emphasis per CCIR recommendation 405-1. This unit also provides an input for summing in an audio subcarrier. Figure 8A shows a block diagram of the video energy dispersal unit.*




Video Energy Dispersal Unit

*The video signal first passes through a variable attenuator and takes two separate paths. One path goes through a buffer amplifier and then is routed through one of four different networks through relay switches which are controlled by the front panel pre-emphasis switch. When the front panel switch is in the 525 flat position, the signal passes through an attenuator whose attenuation is the same as the 525 line pre-emphasis and filter network at the pre-emphasis crossover frequency. When the front panel switch is in the 525 line position, the signal passes through the 525 line pre-emphasis and lowpass filter board. When the front panel switch is in the 625 line position, the signal passes through the 625 line pre-emphasis and lowpass filter board and when the front panel switch is in the 625 flat position, the signal passes through an attenuator whose attenuation is the same as the 625 line filter and pre-emphasis network at the pre-emphasis crossover frequency. The signal then passes through another buffer amplifier and then is injected into the final output video amplifier.*

*The signal also goes through the vertical sync extractor circuitry. If there is no video signal present at the input, the sync loss LED turns on and the triangle waveform generator creates a non-synchronous output triangle waveform of 20 Hz frequency and 2 MHz peak-to-peak deviation.*

*If the video signal is present, the triangle waveform generator produces an output triangular waveform whose inflection points occur at the vertical blanking interval of the input video signal.*

*This dispersal waveform is summed in with the video signal. Also summed in at this point is the audio subcarrier signal if one is used. The composite video, dispersal, and subcarrier signal is then injected to the wideband video amplifier and the composite video then comes out of Pin B.*

*There is a peak detector circuit which allows the peak-to-peak output signal into 75 ohms to be monitored on the mainframe multifunction meter by setting the multifunction switch to the Deviation position.*

Technical Characteristics

Input/Output Impedance
*75 ohms unbalanced*

Input/Output Return Loss
*Greater than 26 dB*

Frequency Response
525 Lines
*±.15 dB of CCIR Rec. 405-1 525-line pre-emphasis response (10 Hz - 4.2 MHz)*
625 Lines
*±.15 dB of CCIR Rec. 405-1, 625 line pre-emphasis response (10 Hz - 6 MHz)*
525 Flat, 625 Flat
*±.15 dB (10 Hz - 6 MHz)*
*±.25 (6 MHz - 8 MHz)*

Video Input Level
*.7 - 2.0 volts peak-to-peak*

Energy Dispersal Waveform (No Video)
Frequency
*20 Hz*
Deviation
*2 MHz peak-to-peak (internally adjustable 2 to 10 MHz p-p)*

Energy Dispersal Waveform (With Video)
Frequency
*25 or 30 Hz synchronous with the vertical blanking interval of the video waveform*
Deviation
*1 MHz peak-to-peak (internally adjustable 0 to 10 MHz p-p)*

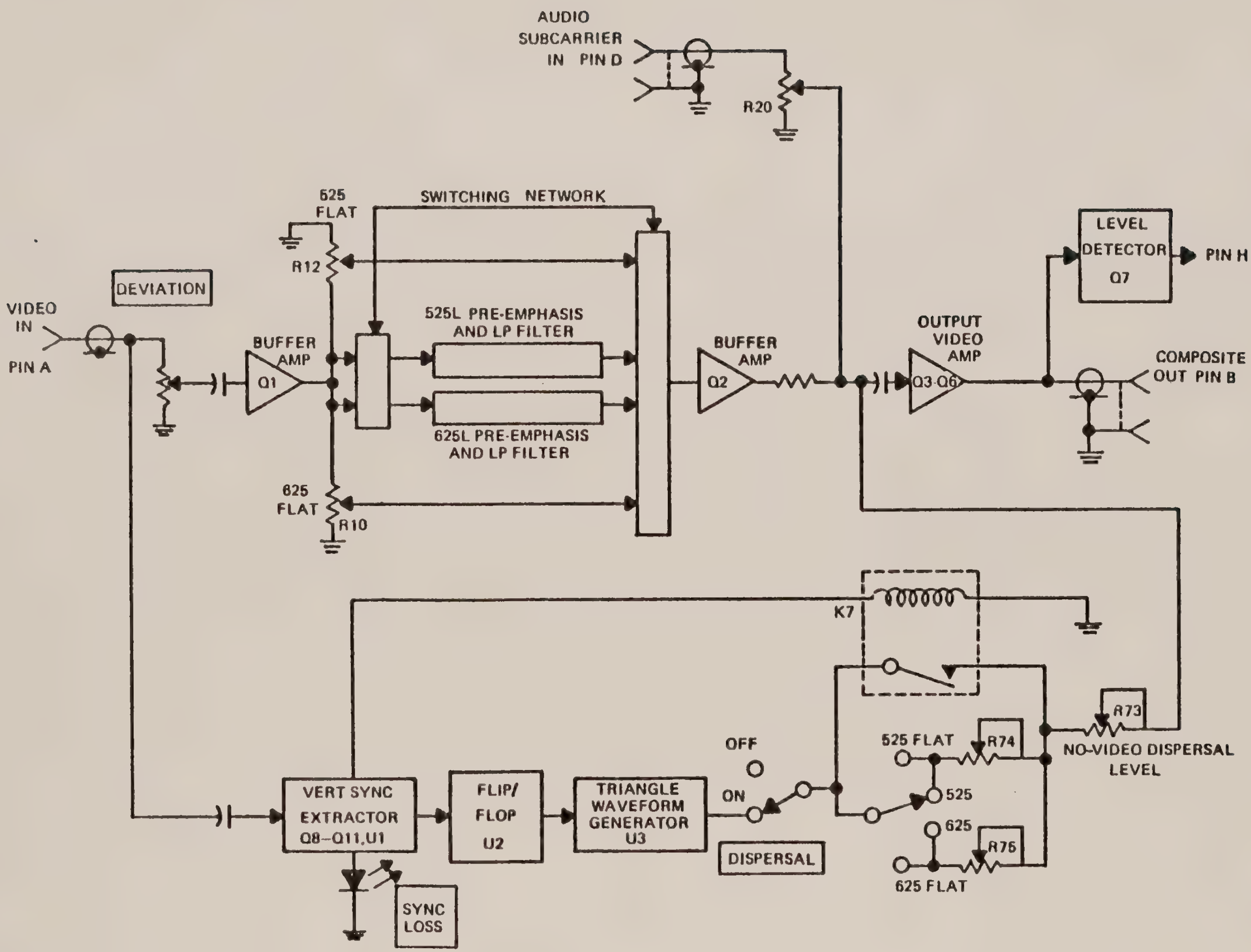



Figure 8A. Video Energy Dispersal Unit Block Diagram

**Controls and Indicators**

a. *Pre-emphasis selects either 525 line or 625 line pre-emphasis and lowpass filter network. In the Flat positions, the same attenuation is provided as at the pre-emphasis crossover frequencies, but the pre-emphasis and filter networks are bypassed. Only those pre-emphasis networks specified by the customer will be supplied in the unit.*

b. *Deviation. This control adjusts the input video level to provide the proper deviation in the modulator. The input video level can be no smaller than .7 volts peak-to-peak but can be as large as 2 volts peak-to-peak. This control is set at the factory to provide the proper deviation in the modulator for 1.0 volt peak-to-peak 525 and/or 625 line video signal. In the event that the input video signal differs from 1 volt peak-to-peak, the following procedure should be used to adjust this control.*
   1. *Input a test tone frequency for the proper line rate video signal at the same peak-to-peak level as the video signal. The signal generator impedance must be 75 ohms unbalanced. Table 15-1 shows the test tone frequencies for the various formats.*
   2. *Switch the dispersal off. Look at the EDU output on an oscilloscope terminated in 75 ohms. Adjust the deviation control for the proper output peak-to-peak level as noted in Table 1A. Apply the video signal and switch the dispersal to IN. Note that the level of the dispersal waveform is set at the factory to provide 1 MHz peak-to-peak deviation in the presence of the video signal and 2 MHz peak-to-peak deviation when the video signal is removed. These levels can be readjusted if required.*

c. *Dispersal. This control switches the dispersal waveform in or out. The normal operating position is IN.*

d. *Sync Loss. This light indicates that the dispersal waveform is not synchronized with the vertical blanking interval of the video signal. When this light is lit, it usually means the input video signal has been removed or is lost or is at too low a level.*

e. *Dispersal Deviation Adjustments. The dispersal deviation adjustments are all internal adjustments set at the factory. The level of the dispersal set at the factory will provide 1 MHz peak-to-peak deviation in the presence of the video signal and 2 MHz peak-to-peak deviation when the video signal is removed, unless the customer has specified otherwise. The no video dispersal deviation can be adjusted from 2 to 10 MHz peak-to-peak by potentiometer R73. Potentiometer R74 will adjust the 525 line dispersal deviation from 0 to 2 MHz peak-to-peak, and potentiometer R75 will adjust the 625 line dispersal deviation from 0 to 2 MHz peak-to-peak.*

## Deviation Information Table

| Format Number | IF Bandwidth MHz | Pre-emphasis Crossover Fx MHz | Peak-to-Peak Deviation at Fx MHz | Level Required Into S-A Modulator at Fx for Peak-to-Peak Deviation All Levels Into 75 Ohms | | | First Carrier Null at Fx Level Into 75 Ohms |
|---|---|---|---|---|---|---|---|
| | | | | V p-p | V rms | dBm | dBm |
| 1 | 17.5 | .7616 | 15 | .293 | .104 | -8.43 | -20.68 |
| 2 | 17.5 | 1.512 | 15 | .293 | .104 | -8.43 | -14.72 |
| 3 | 30 | .7616 | 21.5 | .420 | .149 | -5.30 | -20.68 |
| 4 | 30 | 1.512 | 18.1 | .354 | .125 | -6.80 | -14.72 |
| 5* | 36 | .7616 | 22 | .430 | .152 | -5.10 | -20.68 |
| 6* | 36 | 1.512 | 22 | .430 | .152 | -5.10 | -14.72 |

**Reference to BG 28-72E except as noted by asterisk.**

*Note: For deviations other than those in the above table, the following formulas should be used to determine the level into the Scientific-Atlanta Modulator.*

$V\ p\text{-}p = \triangle F\ p\text{-}p\ (1.957 \times 10^{-2})$ $\quad dBm = 20 \log \triangle F\ p\text{-}p\ (2.526 \times 10^{-2})$

Where: V p-p = peak-to-peak, voltage level into modulator (75 ohms)

dBm = power level into modulator (75 ohms)

$\triangle$F p-p = required peak-to-peak test tone deviation (MHz)

*The transmit alarm unit (Photo No. 6618) is a plug in unit for utilization in the Series 461 Exciters. The alarm unit senses the following signals within the complete exciter chain.*

*a. TX Level*
*b. Power Supplies (5 voltages)*
*c. First LO phase lock*
*d. Second LO phase lock*
*e. Deviation Alarm*

*For IF monitoring, alarm d. is disabled. When one, or all, of these signals fault or an out-of-tolerance condition exists, the exciter alarm unit is triggered. Once triggered, a LED indicator on the front panel of the module illuminates to designate the particular fault and a summary relay contact closure is provided to the rear connector. This contact closure is available for utilization in the overall fault logic.*

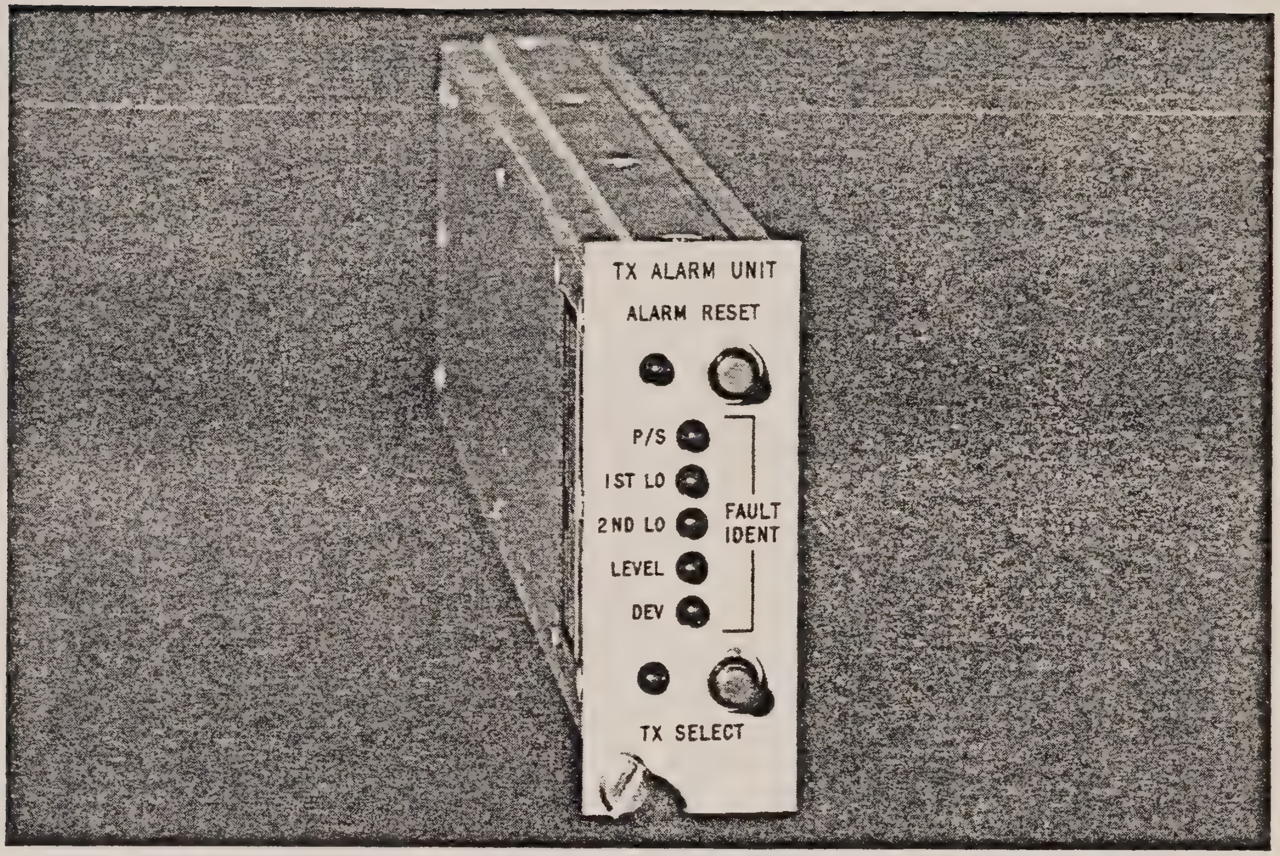
*A Reset pushbutton is used to reset the alarm circuits after a fault has been cleared and a TX Select pushbutton is used to select the desired exciter. The seven LED indicators illuminate to show where the fault occurred and which exciter has been selected.*

*The five Fault Ident indicators will remain illuminated if the fault clears itself. The Alarm indicator, however, will stay illuminated only as long as the fault condition exists.*

*The TX Select indicator is illuminated when the TX Select pushbutton is depressed, and remains illuminated until either a fault occurs or the other exciter is selected.*

**Function**
*Exciter alarm indication and signaling*
**Exciter Functions Monitored**
*+24V dc*
*-24V dc*
*-20V dc (upconverter)*
*+12V dc*
*-12V dc*
*First LO phase lock (upconverter)*
*Second LO phase lock (upconverter)*
*TX Level*
*Deviation*
**Voltage Alarm**
*±30% from nominal value*
**Phase Lock Alarms**
First LO Alarm
*Upon loss of -20V dc from first LO in upconverter*
Second LO Alarm
*Upon receipt of phase lock loop search from second LO in upconverter (typically 18 volt peak-to-peak sawtooth waveform)*
**TX Level Alarm**
*Voltages >+0.2 volt or < -0.2 volt*

**Dev Alarm**
*Current >0.1 mA into Q16 base*
**Outputs**
Alarm
*Relay contact closure and TTL logic signal > +2.4 volts*
TX Select
*Switch closure to signal return*
**Inputs**
Receiver Voltage
*+24V dc and -24V dc at 10 mA (sense only)*
*+12V dc and -12V dc at 200 mA*
*-20V dc at 10 mA (sense only)*
First LO
*-20V dc at 2 mA from upconverter*
Second LO
*Phase lock search signal, 60 Hz, 18V peak-to-peak sawtooth*
TX Level
*Normal voltage -0.2 to +0.2 volts: Alarm condition outside these limits*
Dev Alarm
*Input current > 0.1 mA into Q16 base*
TX Select
*Voltage > 2.4 volts turns on TX Select indicator*




Exciter Alarm Module with Fault Indicators

**Program/Cue Auxiliary Chassis** *The program/cue auxiliary mainframe is the audio section of the television uplink, downlink, or uplink and downlink systems depending on the module configuration. This mainframe houses the subcarrier modulators in an uplink system and can also house demodulators in a downlink system if there is no room in the receiver chassis.*

*All input and output signals to and from the four modules pass through connectors on the rear panel, shown in Table 32-2.*

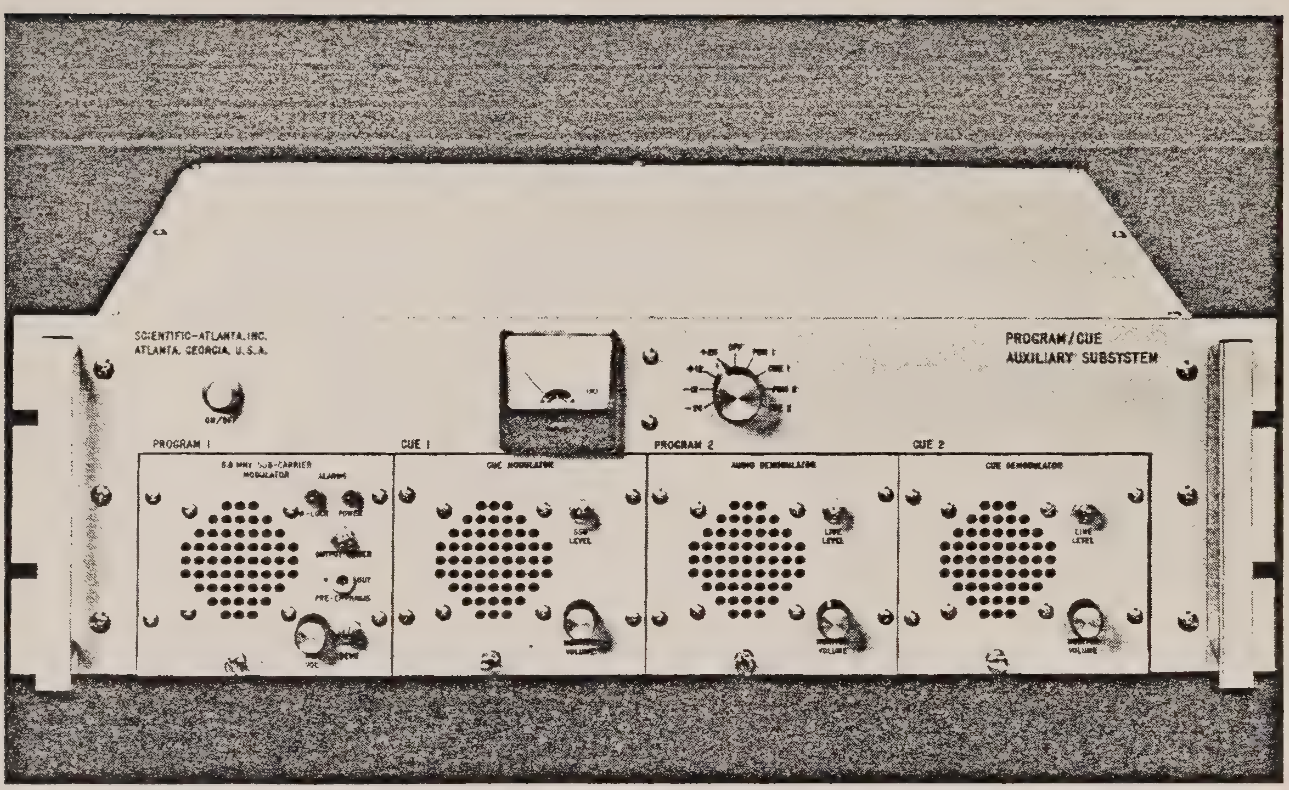
**Front Panel Meter and Switch** *A meter and selector switch on the mainframe front panel permits monitoring and rapid checking of the circuits in the assembly during operation. The Meter Function switch may be left in any position during operation. In the Off position, the meter is completely disconnected. The switch monitors +24V, +12V, and all audio levels.*

**Power Supply** *Each of the modules are powered by a single power supply located at the right rear of the chassis. The supply delivers +24V dc and +12V dc from an ac line input voltage.*

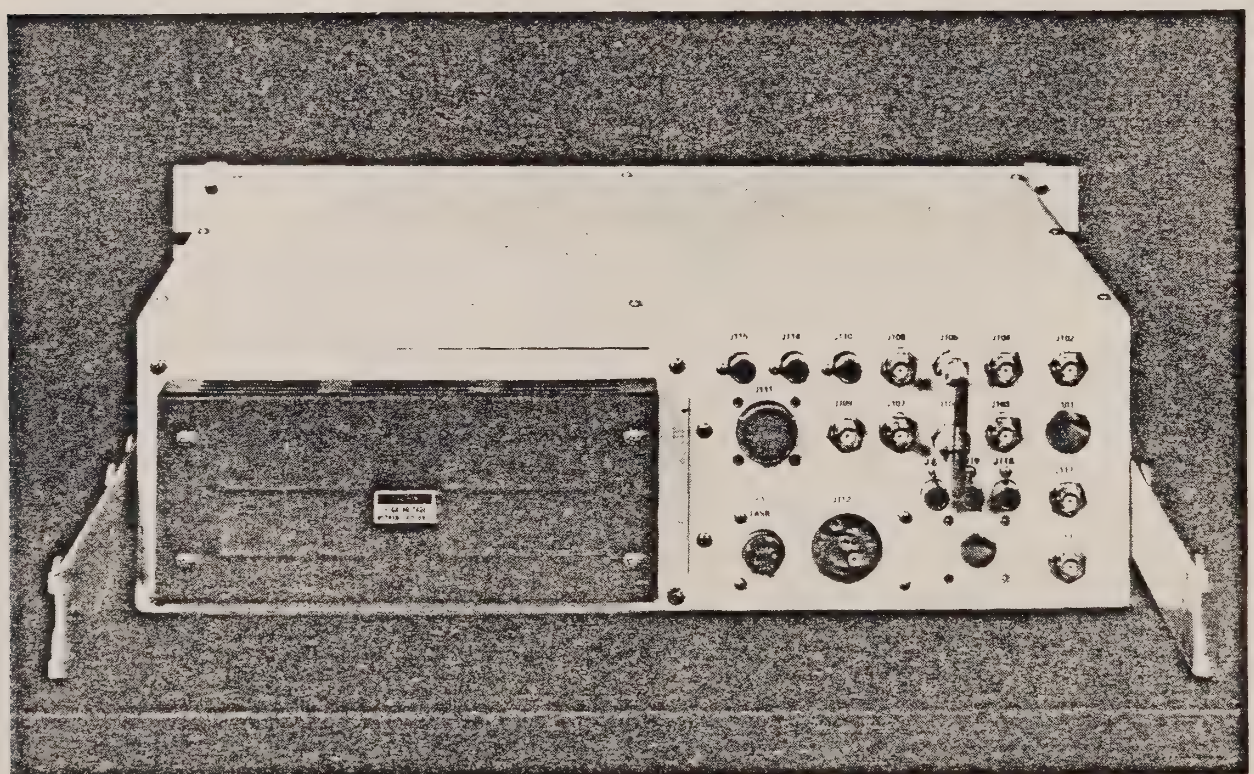
**Mainframe Controls and Indicators** *A meter, a power switch, and a meter switch are on the upper part of the assembly mainframe. The table below describes their functions.*

**Assembly Mainframe Controls and Indicators Table**

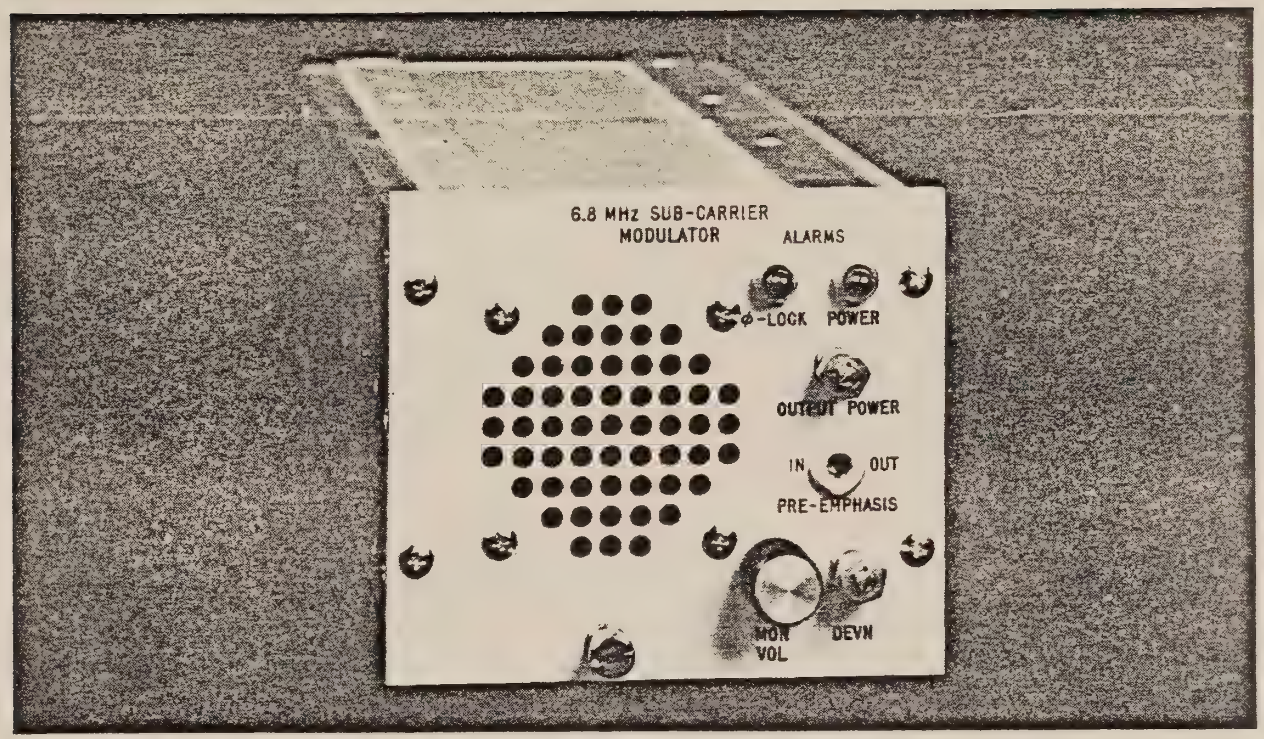
| Control/Indicator | Position | Function |
|---|---|---|
| Power On/Off switch | ON (lit) | AC power applied to assembly |
| | OFF (dark) | AC power removed from assembly |
| Meter Function switch | OFF | Meter disconnected |
| | -24 | Meter reads voltage on receiver -24V dc bus |
| NOTE | | |
| Read voltages on top meter scale. | +12 | Meter reads voltage on +12V dc bus |
| | +24 | Meter reads voltage on +24V dc bus |
| | Program 1<br>Cue 1<br>Program 2<br>Cue 2 | These switch positions connect the meter to read various signal levels at the outputs and inputs of the modules plugged into the mainframe. Refer to the operating and level setting instructions in this section and to the individual module sections in this instruction manual for further information. |




Program/Cue Auxiliary Mainframe with Audio Modulators and Demodulators



Rear Panel Program/Cue Auxiliary Mainframe




**Description** *The subcarrier modulator is a plug-in module intended for operation with the Scientific-Atlanta Series 461 Exciter. The program and cue information is frequency modulated at ~6 MHz in the subcarrier modulator. Plug-in filters and pre-emphasis boards allow this unit to operate with a 5, 10, or 15 kHz top audio frequency and various pre-emphasis networks.*

**Circuit Description** *Figure 9A is a block diagram showing the relationship of the circuits in the subcarrier modulator.*

### Controls and Indicators

| Control/Indicator | Function |
|---|---|
| Alarms | |
| Phase Lock | Indicates loss of phase lock |
| Power | Indicates loss of output power |
| Output Power | Controls the amplitude of the output power |
| IN-OUT PRE-EMPHASIS | DPDT switch, allows pre-emphasis to be switched in or out. Normal operating position is in |
| DEVN | Adjusts the frequency deviation of the output signal |
| MON VOL | Controls the audio volume from the speaker |

Modulation Bandwidth
*50 Hz to 5, 10, and 15 kHz*
Pre-Emphasis
*75 µs for 15 kHz*
*CCITT J-17 for 10 kHz*
Deviation
Program
*137 kHz peak @ 1 kHz test tone*
Cue
*51 kHz peak @ 1 kHz test tone*
Input Level
*0 to +10 dBm*
Input Impedance
*600 ohm balanced*
Input Return Loss
*26 dB*
20 to 500 kHz Attenuation (15 kHz)
*40 dB*
15 to 500 kHz Attenuation (10 kHz)
*40 dB*
Frequency Stability
*±1.0 kHz/24 hours*
*±3.0 kHz/30 days*
Level Stability
*±0.15 dB/24 hours*
*±0.25 dB/30 days*
Deviation Stability
*±0.30 dB/24 hours*
*±0.40 dB/30 days*
Baseband Flatness
*±0.40 dB (50 Hz - 15 kHz)*
*±0.30 dB (50 Hz - 10 kHz)*
Modulation Linearity
*1% over its 450 kHz occupied bandwidth*

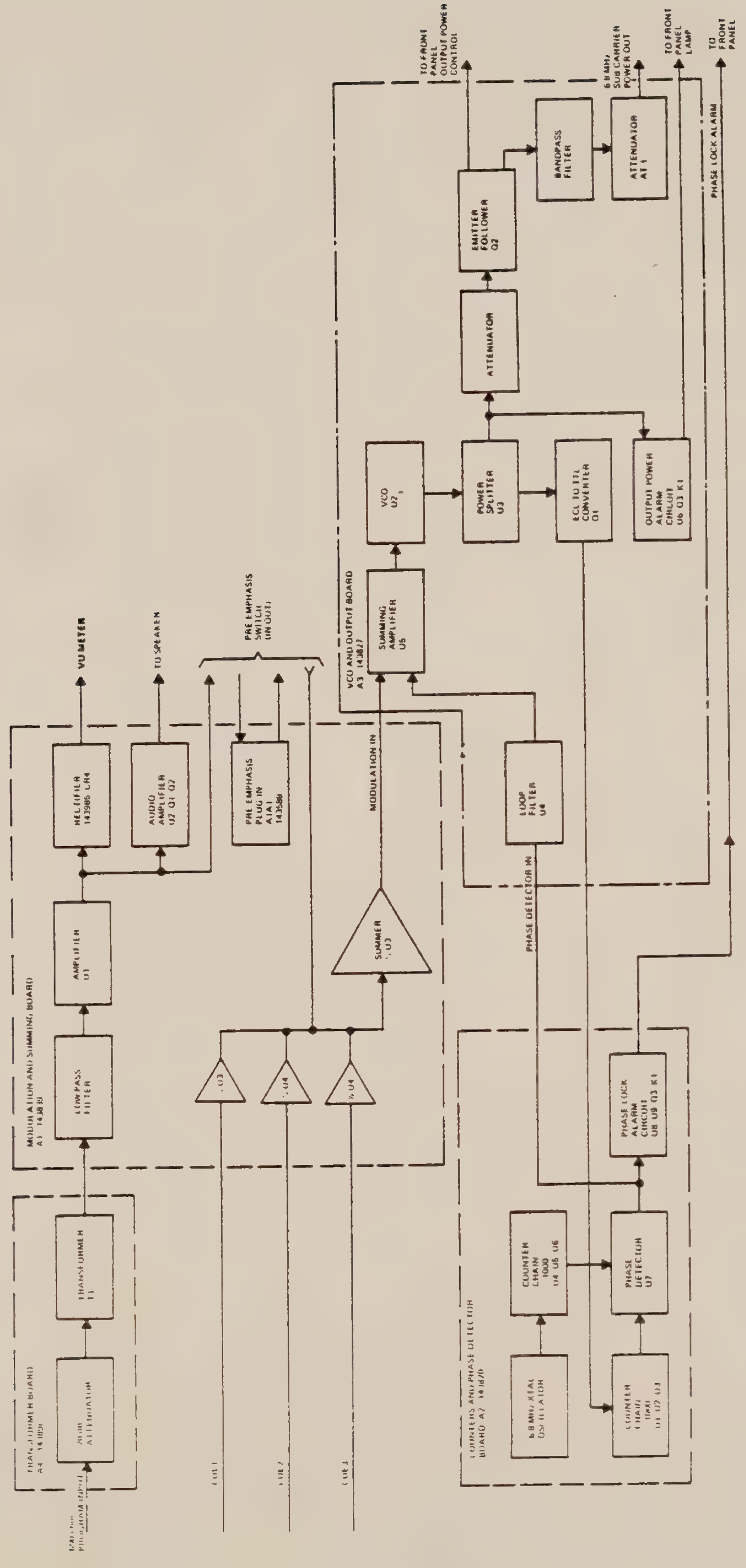



Figure 9A. 6.8 MHz Subcarrier Modulator Block Diagram

# VIDEO THRESHOLD EXTENSION for SMALL APERTURE EARTH STATIONS

Elias Livaditis
and
Heinz Wegener

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Abstract** The use of small aperture earth stations (approximately 5 meter diameter antennas) places severe requirements on receiver electronics to maintain adequate signal to noise ratio with current EIRP values from most satellites. One major purpose of the small aperture earth station is to reduce cost; therefore, the use of cooled parametric amplifiers would tend to offset costs savings achieved by using small aperture antennas. Even the recent advances in low noise figures in gallium arsenide FET amplifiers does not provide sufficient margin in all situations.

FM threshold extension in small aperture antenna earth stations allows acceptable video performance in otherwise marginal signal strength areas while still maintaining appropriate link margins. This paper discusses the subjective and objective nature of threshold relative to the domestic video satellite transmission format, illustrates the effect of reduced S/N on picture quality, and provides a discussion of the effects of bandwidth reduction on threshold. Threshold curves of various IF bandwidths with and without threshold extension are presented.

**Introduction** Prior to approval of the use of antennas as small as 4.5 meters for reception of domestic video, threshold was not a very important factor to be considered in earth station design. The following information relates primarily to the domestic video format which utilizes a subcarrier to carry the audio information. The purpose of this paper is to discuss the following items relative to threshold.

A. A general concept of threshold and what elements of an earth station control operation above threshold.
B. Subjective effects of threshold on video and audio.
C. The effects of modulation on threshold and threshold measurement techniques.
D. Subjective and objective threshold extension achieved using Scientific-Atlanta's threshold extension demodulator.
E. The effects of IF bandwidth reduction on threshold and video distortions due to bandwidth reduction.
F. Benefits of using threshold extension.

**A General Concept of Threshold**

A detailed description of the FM threshold phenomena is beyond the scope of this paper but can be investigated in several text books.[1&2] If an experiment were made on an FM demodulator detecting an FM modulated carrier with a modulation index greater than $\sqrt{2/3}$ [3] and broadband noise were added to the carrier prior to demodulation, the signal-to-noise ratio (S/N) versus carrier-to-noise power ratio (C/N) curve of Figure 1 would result.

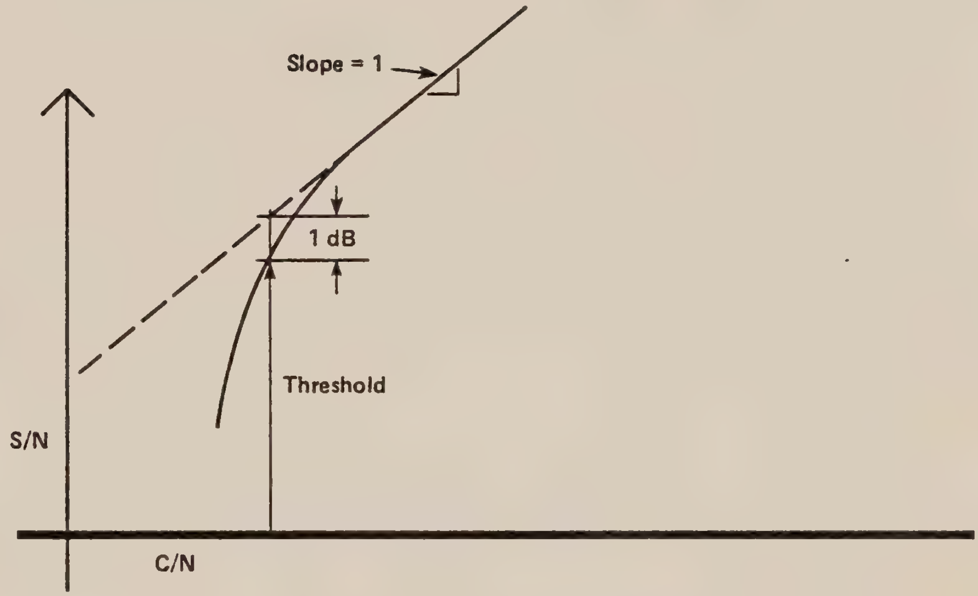



Figure 1. S/N versus C/N of an FM Modulated Carrier.

When the carrier level is much greater than noise, a 1 dB carrier level change results in a 1 dB S/N ratio change. However, when the carrier level gets close to the noise a phenomena called threshold occurs causing the S/N to decrease more rapidly than a 1 for 1 basis. The point at which the S/N curve departs from a 1 to 1 asymptote by 1 dB is often called the threshold point of the demodulator. This threshold effect is due to noise adding in a certain phase and amplitude with the carrier so as to cause what appears to be an instantaneous frequency shift at IF which appears as an impulse out of the discriminator (impulse noise). Noise can be characterized as having a flat freqeuncy spectrum and an amplitude which has a Gaussian distribution (often called white noise). Therefore, if the total noise power is close to the carrier power there is a certain amount of instantaneous noise that is a much greater and also a much smaller level than the RMS noise level. As the carrier level gets closer to the RMS noise level, it is statistically possible for

1 Taub and Schilling, Principles of Communications Systems, (McGraw-Hill Book Company, 1971), pp.320-364.

2 Mischa Schwartz, Information Transmission Modulation and Noise, (McGraw-Hill Book Company, 1959), pp. 304-305.

3 Taub and Schilling, p. 321.

more and more occurrences of carrier and noise summation to cause impulse noise out of the demodulator. This greatly increases the total baseband noise power as shown in the curve of Figure 1. Impulse noise is present well before the defined threshold point but its occurrence is infrequent and does not drastically affect the demodulated noise power. Some additional information that is generally true relative to threshold:

1. Since the statistics at threshold relate to the total pre-detection noise power the threshold point will occur at a lower carrier level if the pre-detection bandwidth is reduced. (as long as sufficient bandwidth is allowed to pass the modulated carrier without distortion.)
2. As the modulation index (B) is increased the S/N increases but threshold occurs sooner.
3. Threshold is only important if the C/N at which threshold occurs still provides an acceptable S/N of the demodulated signal.

**Equipment in an Earth Station which Controls Operation above Threshold**

Once an earth station is operational the noise generated due to the antenna and the low noise amplifier (LNA) is fixed (except in instances of some unusual atmospheric conditions). In order for threshold to occur the carrier level must reduce to within a certain value of this noise "floor". In general, an antenna and LNA can always be selected to keep the carrier well above the noise even under worst case signal level degradations. For domestic earth stations a worst-case carrier level degradation of 3 to 4 dB has been established. This degradation is due primarily to (among other things):

1. Variations in transmitted power from the satellite (effective isotropic radiated power, EIRP).
2. Variations in atmospheric attenuation.
3. Antenna pointing error (either static or environmentally induced).

In general, this worst case degradation occurs infrequently but a satisfactory signal should be provided during this carrier level reduction.

The cause of threshold is then due to the ratio of the signal power to the noise floor which is established by the antenna and LNA of the station. To accurately relate this value a term often used is carrier power-to-noise-power density ratio ($C/N_o$). The equation for $C/N_o$ expressed in dB-MHz is:

$$C/N_o = EIRP - L_p + G/T - K$$

where
- $C/N_o$ = Carrier power to noise power density ratio (dB MHz)
- EIRP = Effective Isotropic Radiated Power (dBW)
- $L_p$ = Path loss (dB)
- G/T = Receive system gain/noise temp (dB/°K)
- K = Boltzmanns constant (−168.6 dBW/MHz/°K)

where
- $G/T = G_A - 10 \log t_s$
- $G_A$ = Antenna Gain at a reference point (dB)
- $t_s$ = System noise temperature referenced to the same point as the gain of the antenna (°K)

$C/N_0$ relates the carrier power to the noise power in a unit bandwidth (1 MHz in this case). To convert $C/N_0$ to the more commonly used carrier to noise ratio (C/N) which is a ratio of carrier power to the total noise power in a defined bandwidth the following equation is used:

$$C/N = C/N_0 - 10 \log (B_{IF})$$

where C/N is expressed in dB

$C/N_0$ = Carrier power to noise power density ratio (dB MHz)

$B_{IF}$ is the pre-detection noise bandwidth (MHz)

Another commonly used term is C/T which relates the carrier level to the system noise temperature of the station and differs from $C/N_0$ only by Boltzmann's constant.

$$C/T = C/N_0 + K$$

where C/T is in terms of dBW/°K

The advantages of discussing threshold in terms of $C/N_0$ or C/T is that these terms relate directly to the ratio of the carrier level to the noise floor of a system and are not dependent on pre-detection bandwidths. Therefore if the threshold is expressed as a function of C/T or $C/N_0$ the actual desired final information can be derived; how close to the noise floor can the carrier be before degradations due to threshold occur. This is especially useful when comparing performance of different receivers with different pre-detection bandwidths or when studying the threshold differences of various bandwidths.

The effect of a carrier close to the noise floor of an earth station manifests itself in the demodulation of the signal in the receiver. How the demodulator responds to the carrier under this condition determines when the video signal becomes objectionable due to the threshold phenomena.

**Subjective Effects of Threshold**

The subjective effect on a demodulated signal which has impulse noise on it is the appearance of horizontally elongated black and white dots on a video signal observed on a television set and audible clicks on an audio signal.

In the case of a video signal, typical program material tends to mask impulse noise slightly when it first occurs due to the movement and changing nature of the program. In general impulse noise will be more objectionable on a long fixed pattern than with a moving scene. The transition from a relatively good picture to a generally unacceptable one occurs with a fairly small (1-2 dB) reduction of carrier level once the beginning of the threshold region is reached. Clamping the video to a reference level (both for removal of the energy dispersal waveform and dc restoration) will tend to further distort the viewed signal in the presence of impulse noise in that an impulse during the clamping period will temporarily "shift" the dc level of a line causing a smearing effect. When well into threshold (4-6 dB below the threshold point) sync loss typically occurs due to a massive influx of impulses distorting the vertical blanking interval.

Discussion on audio degradations will be relative to the domestic video format where a subcarrier (typically at 6.2 or 6.8 MHz) is used to carry the video associated audio.

In the audio case the threshold effect manifests itself in audible clicks which increase in loudness and frequency of occurrence as the baseband noise floor comes up. In addition when the demodulator discriminating the main carrier thresholds it is difficult to predict the subcarrier demodulators performance since the baseband noise about the subcarrier can no longer be considered Gaussian. In general once the main demodulator thresholds, noticeable degradations of the audio subcarrier demodulator will occur even if the subcarrier level is well above the baseband noise floor. The audio threshold has a subjective advantage in that during heavy modulation the amount of impulse noise increases but so does the level of the audio information which tends to mask impulse noise slightly.

### Effects of Modulation on Threshold

It has been shown [4] that if the carrier is offset from the center of the pre-detection bandwidth both the amplitude and frequency of occurrence of the impulse noise generated increase. Therefore any modulation (which will cause the carrier to move from the center) causes an increase in impulse noise and effectively causes threshold to occur sooner.

If the pre-detection bandwidth is too narrow to accommodate the required bandwidth of the modulated carrier, the carrier will occasionally go to a frequency at the edge of the filter causing a momentary reduction in the carrier amplitude. If the carrier level was close to the threshold point the reduction in carrier level due to the narrow filter can momentarily cause a threshold condition to occur creating impulse noise. This is further aggrevated by the fact that the carrier is maximally offset from its center frequency which enhances the threshold phenomena as was previously mentioned.

### Threshold Measurement Techniques

In general the end object of determining the threshold point of a receiver is to determine how low the level of the received carrier can be relative to the earth station noise floor before impulse noise causes the picture to become objectionable. This is the subjective threshold because a picture is determined to have objectionable distortions due to impulse noise by visually judging the picture. Subjective threshold will depend on the viewer and the amount of interest he has in the programming. However, in future discussions the subjective threshold will be defined as the $C/N_0$ or C/T where impulse noise becomes readily perceptable but occurs rather infrequently as noted on a television set with "typical" programming. Also, in the information that follows the following video format (RCA Satcom) will be the basis for any conclusions made unless other deviation parameters are stated.

Video Deviation (.7616 MHz Test Tone) = 10.75 MHz peak
Carrier Deviation by the 6.8 MHz Subcarrier = 2 MHz peak
Subcarrier Deviation (1 kHz test tone) = 75 kHz peak
Dispersal Deviation with Video = 1 MHz peak-to-peak
Video Pre-Emphasis = 525 line per CCIR 405-1
Audio Pre-Emphasis = 75 $\mu$sec

Table 1 RCA Satcom Deviation Parameters

4 Taub and Schilling, p. 335.

The information that follows is intended to help relate objective threshold as determined by making measurements of baseband noise to subjective threshold. The conclusions drawn relate in general to measurements made using a Scientific-Atlanta Model 414 Video Receiver and may not be applicable to other manufacturers receivers.

**Static S/N Measurements**

This technique is the most commonly used technique to measure S/N.

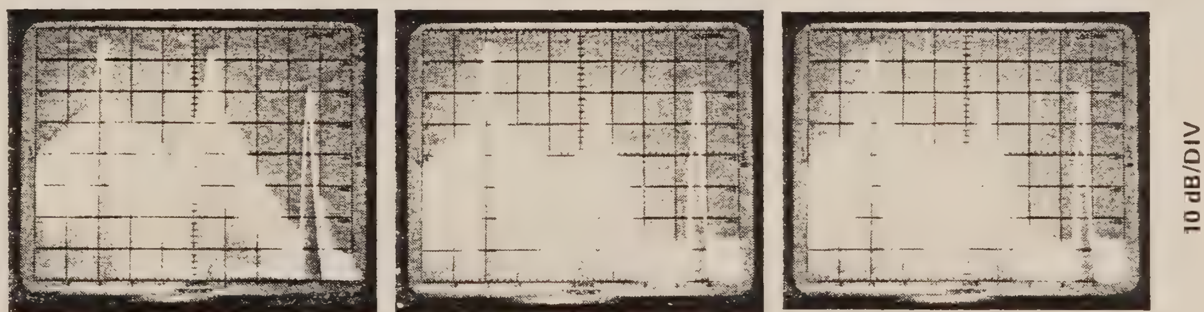
1. The proper deviations of the subcarrier and main carrier are set.
2. Using the waveform monitor the video level out of the receiver is set to 1.0V peak-to-peak and the peak-to-peak level of the white reference pulse recorded.
3. The level of the audio test tone out of the received is measured.
4. The audio, video, and dispersal modulation is removed by terminating these inputs to the modulator.
5. A reference on the signal attenuator at which carrier is equal to noise is established. In order for this to be meaningful the noise bandwidth of the noise source (which must be greater than the receiver bandwidth) or the noise bandwidth of the receiver must be known.
6. The level of the carrier is adjusted for different C/T ratios and the rms noise power at baseband is measured. For video this is measured through standard low pass (usually 4.2 MHz), high pass (4 to 10 kHz), and weighting filters. For audio it is frequently an unweighted measurement.

The main advantage to this test is that for video the characteristics of the filters are very well defined so that the curves resulting from this test are easily and consistently repeatable. The disadvantage is that the threshold point determined from this test will not in general relate to the subjective threshold. This is due to the fact that there is no modulation on the carrier and as was stated earlier a modulated carrier thresholds sooner than an unmodulated carrier. Finally, although weighting filters account for the visual effects of thermal noise they don't necessarily account for the visual effects of impulse noise.

**Dynamic S/N Measurements**

This test is conducted similarly to the static test except that the carrier is modulated by several frequencies which are filtered out before the baseband noise power is measured.

Two sources of modulation that can be added without additional filtering are the energy dispersal waveform (which is filtered out by the high pass filter) and the 6.8 MHz subcarrier (which is filtered out by the low pass filter).




0 3.58 MHz 6.8 MHz
Full Field Color Bar

0 3.58 MHz 6.8 MHz
Typical Program 1

0 3.58 MHz 6.8 MHz
Typical Program 2

Figure 2. Pre-Emphasized Video Spectrums.

In addition to the dispersal waveform and the subcarrier another excellent choice of a frequency that should modulate the carrier and be filtered out before noise measurements are made is the color subcarrier frequency at 3.58 MHz. Figure 2 shows photographs of the average pre-emphasized baseband of typical program material and a full field color bar test signal. The photographs were taken over a 2 second scan period. In both photographs a heavy concentration of energy is shown around 3.58 MHz which seems logically correct. Some experimentation should be conducted to determine what amount of deviation of the 3.58 MHz signal best allows accurately relating the objective threshold to a subjective threshold on typical programming material.

**Noise Insertion Measurements**

The noise insertion technique allows fairly accurate determination of S/N above threshold. However, this technique provides erroneous indications of threshold because the character of noise changes due to impulse noise.

**Subjective Color Bar Tests**

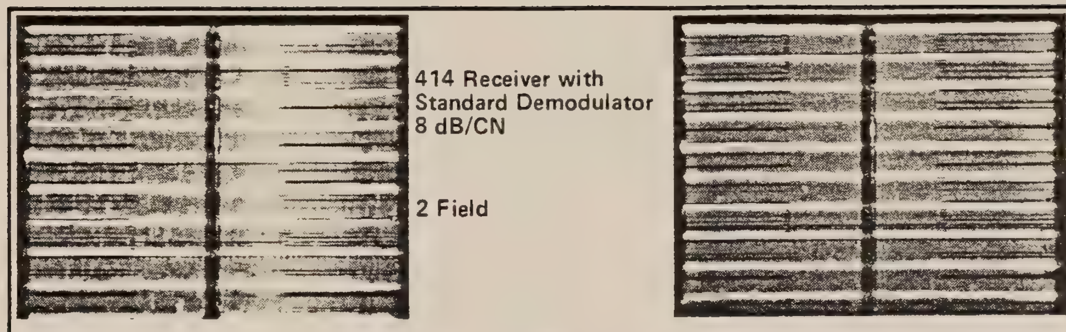
This test merely involves modulating the carrier with the subcarrier, dispersal and a full field color bar test signal and noting at which C/N impulse noise becomes barely perceptible on a television monitor. Although this is a good way of comparing receivers it is actually a worst-case modulation situation as compared to typical program material. Figure 2 somewhat substantiates this by comparing the baseband spectrum of a full field color bar signal with 2 different video signals which were taken from off-the-air programming. The program video was derived from a local video carrier which was demodulated using a Scientific-Atlanta Model 6250 TV Demodulator. The point at which impulse noise first appears on the television monitor with a full field color test signal occurs at a C/T 2-3 dB above where an average viewer may begin to notice impulse noise on typical program material. Also, this test is somewhat dependent on the experience of the viewer in noticing when impulse noise first appears.

**Threshold Extension**

Various techniques of extending the threshold of an FM demodulator can be used. The object of threshold extension is to reduce the point at which threshold occurs assuming the S/N ratio is acceptable at the reduced C/T at which threshold now occurs. There are no currently known operational techniques that provide an improvement of S/N above the theoretical value. Only the point of occurrence of impulse noise can be changed. With the threshold extension demodulator the carrier level relative to the earth station noise floor can be 2 dB lower than the conventional demodulator before impulse noise due to threshold appears on the demodulated signal.

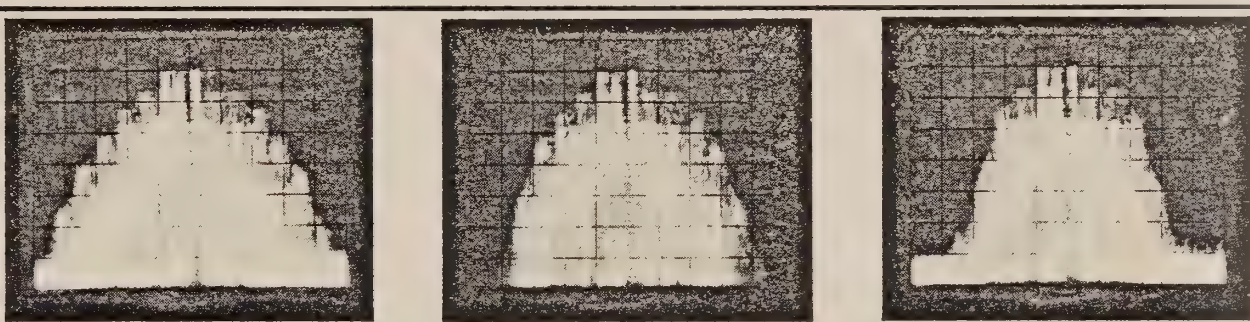
Observations of the video threshold using threshold extension and the audio threshold (no audio threshold extension technique was used) shows that video threshold extension achieved by the Scientific-Atlanta TED still allows operation of the audio signal above its threshold. Further video threshold extension might allow video operation above threshold but with the audio signal well into threshold.

Another way of looking at impulse noise reduction is shown in Figure 3 where two fields of a 10 step modulated pedestal test waveform are displayed on a Tektronix 1458 waveform monitor with the 3.58 MHz signal filtered out.




Photographs are based on 10 step linearity test signal with subcarrier, as viewed on a Tektronix waveform monitor using low pass response.

Figure 3. Example of TED Impulse Noise Reduction.



36 MHz Filter | 30 MHz Filter | 25 MHz Filter

Vertical Scales: 10 dB/DIV; Horizontal: 5 MHz/DIV; Center = 70 MHz
(50% APL Color Bars Test Signal, 6.8 MHz Subcarrier, and 1 MHz p-p Energy Dispersal, Modulating the Carrier)

Figure 4. Effects of Bandwidth Reduction on Modulated Spectrum

### The Effects of IF Bandwidth Reduction on Threshold

Bandwidths narrower than full 36 MHz are occassionally used or recommended to be used in receivers for reception of 36 MHz video. Although reduced bandwidths do not result in an improved S/N ratio at a certain C/T they do result in allowing operation to a lower C/T before threshold occurs. The reason for this is that although threshold still occurs at about the same C/N the total noise power (N) is reduced by reducing the noise bandwidth therefore allowing a lower carrier level (C) before the C/N at which threshold occurs is reached. Reception of video through narrower filters than theoretically allowable (using Carson's bandwidth rule) is being presently used by INTELSAT for ½ transponder video (17.5 MHz IF filters) but the audio is transmitted on a separate carrier. Following is some information on the effects on the domestic video modulation scheme (as defined earlier) of reduced bandwidth. To do a comparison of how low the carrier can be relative to the noise floor of the earth station with various bandwidths, S/N is plotted as a function of C/T (or $C/N_O$).

### Filters Used

The filters used were tuned to be within the INTELSAT masks for INTELSAT 36, 30, and 25 MHz filters.[5] The measured noise bandwidths of these filters are 39.4 MHz, 31.9 MHz, and 23.6 MHz for the 36, 30, and 25 MHz filters respectivily.

5 "Performance Characteristics of Earth Stations in the INTELSAT IV-A System", INTELSAT Document BG-11-40E, W/9/74, 20 September 1974, pp. 45-46.

**Effects of Bandwidth Reduction on Video and Audio Distortion**

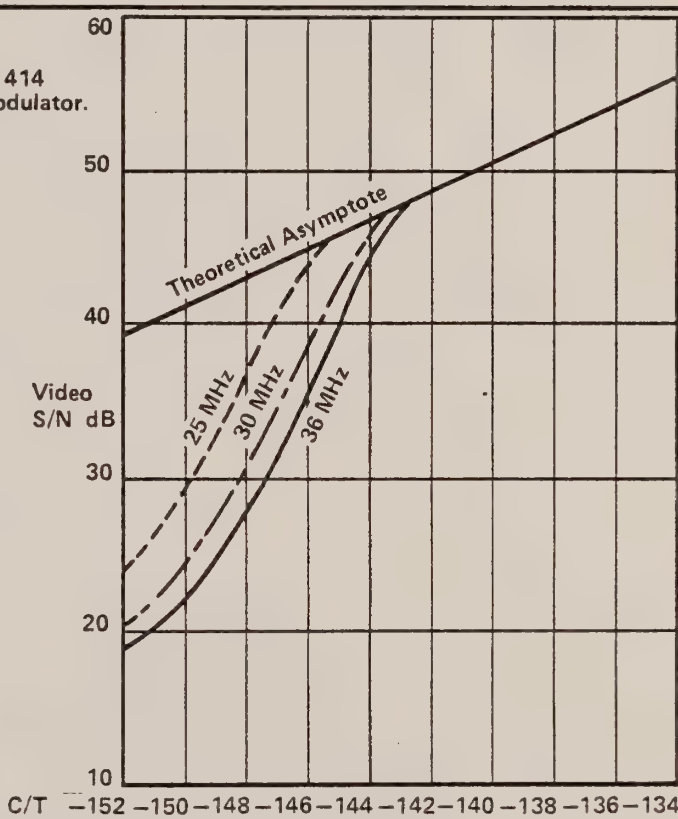
Although a comprehensive presentation on video distortions is beyond the scope of this paper some general comments can be made. Figure 4 shows three spectrum photographs of a carrier modulated with a 50% APL color bar video test signal and the dispersal and subcarrier deviations of Table 1. Some moderate spectrum truncation is seen with the 30 MHz filter while severe spectrum truncation occurs for the 25 MHz filter. The video distortion differences as noted out of the receiver when going to a 30 MHz IF filter were not readily noticeable as compared to a 36 MHz IF filter but were quite obvious with the 25 MHz filter primarily in the area of short-time distortion and chrominance to luminance gain inequality at certain APL's.

The amount of additional detectable audio distortion for the 30 MHz filter was negligible but, with the 25 MHz filter resulted in annoying audible interference at certain APL video test signals.

These results tend to be consistent with those obtained by G.W. Beakley and R.E. Flory [6] in filter bandwidth reduction tests using video signals transmitted on the ANIK satellite (which uses deviation parameters somewhat similar to the domestic video parameters.)

**Figure 5.**
**Measured threshold data of a Scientific-Atlanta 414 Video Receiver equipped with a standard demodulator.**

Noise weighting and low pass per CCIR 421-3
C/T for 0 dB C/N:
- - - 25 MHz, −154.9 dBW/°K
— - — 30 MHz, −153.6 dBW/°K
——— 36 MHz, −152.7 dBW/°K




6 G.W. Beakley and R.E. Flory, "Television by Satellite Experiment Conducted at Scientific-Atlanta" (Princeton, N.J.: RCA David Sarnoff Research Center).

**Effects of Bandwidth Reduction on Video and Audio Threshold**

Figures 5 and 7 are video S/N vs. C/T curves for the three IF bandwidths without and with threshold extension respectively. Figures 6 and 8 show the audio S/N vs. C/T curves. The video S/N curves were made with subcarrier and dispersal deviation on the carrier and the audio S/N curves were made with the main carrier modulated with a full field color bar test signal. The audio S/N is an unweighted measurement.

Figure 6.
Measured audio threshold data of a Scientific-Atlanta 414 Video Receiver equipped with a standard demodulator
Unweighted Audio S/N
C/T for 0 dB IF C/N:
– – – 25 MHz, −154.9 dBW/ °K
–·–·– 30 MHz, −153.6 dBW/ °K
——— 36 MHz, −152.7 dBW/ °K

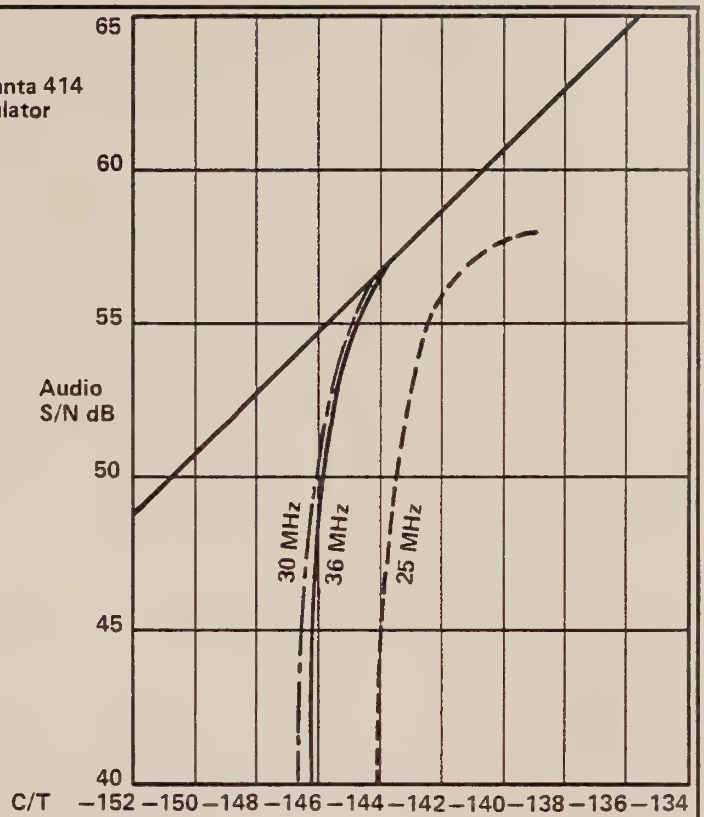


Figure 7.
Measured threshold data of a Scientific-Atlanta 414 Video Receiver equipped with a threshold extension demodulator.

Noise weighting and low pass per CCIR 421-3

C/T for 0 dB IF C/N:
- - - 25 MHz, −154.9 dBW/ °K
— - — 30 MHz, −153.6 dBW/ °K
——— 36 MHz, −152.7 dBW/ °K

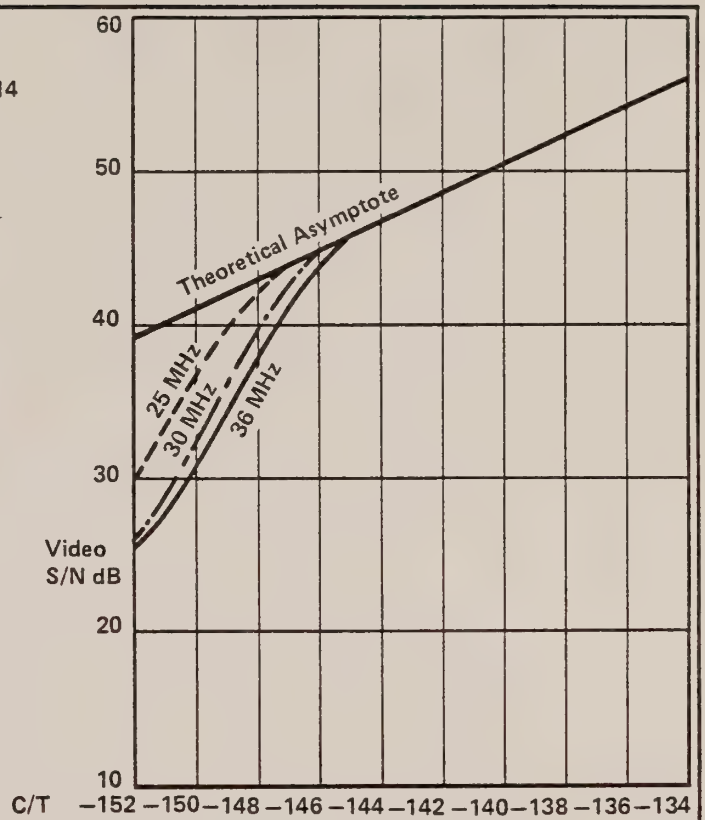



Figure 8.
Measured audio threshold data of a Scientific-Atlanta 414 Video Receiver equipped with a threshold extension video demodulator.

Unweighted Audio S/N

C/T for 0 dB IF C/N:
- - - 25 MHz, −154.9 dBW/ °K
— - — 30 MHz, −153.6 dBW/ °K
——— 36 MHz, −152.7 dBW/ °K

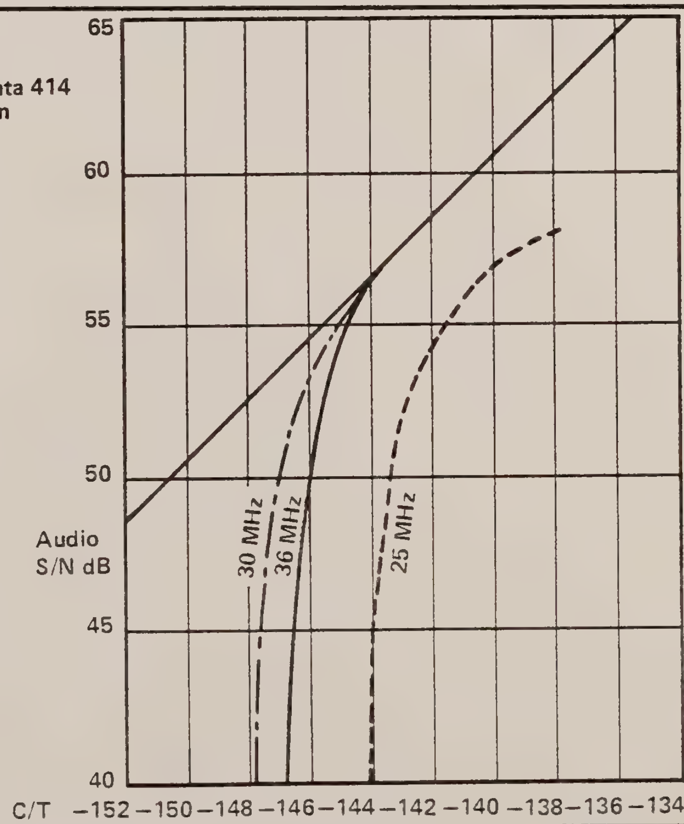


Table 2 summarizes the points at which impulse noise became perceptible for both typical programming and a full field color bar test signal. These points are not necessarily unacceptable video performance points as was noted earlier. Also these points do not define a firm boundary below which the video signal becomes unacceptable. Note also that these points occur above the 1 dB S/N curve departure from the 1 for 1 asymptote. It is probably safe to state that at the points of just perceptible impulse noise few viewers would complain about unsatisfactory video performance due to the amount of impulse noise present. The point at which there might be moderate complaints about the amount of impulse noise on the video is probably closer to the 1 dB departure from the 1 for 1 asymptote and the amount of impulse noise rapidly increases below this point.

| Filter (Demodulator) | Dynamic 1 dB Departure from Linear | | Static 1 dB Departure from Linear (No Modulation) | | Perceptible Impulse Noise Points: Program Material | | Perceptible Impulse Noise Points: Color Bars (75%) | |
|---|---|---|---|---|---|---|---|---|
| MHz | (C/T)dBW/°K | ($C/N_o$)dB MHz | (C/T)dBW/°K | ($C/N_o$)dB MHz | (C/T)dBW/°K | ($C/N_o$)dB MHz | (C/T)dBW/°K | ($C/N_o$)dB MHz |
| 36 Standard | −143.4 | 25.2 | −143.4 | 25.2 | −142.7 | 25.9 | −140.7 | 27.9 |
| 36 TED | −145.9 | 22.7 | −146.2 | 22.4 | −144.7 | 23.9 | −142.7 | 25.9 |
| 30 Standard | −144.2 | 24.4 | −144.3 | 24.3 | −143.6 | 25.0 | −141.6 | 27.0 |
| 30 TED | −146.7 | 21.9 | −147.1 | 21.5 | −145.6 | 23.0 | −143.6 | 25.0 |
| 25 Standard | −146.0 | 22.6 | −145.6 | 23.0 | −144.9 | 23.7 | −140.4 | 28.2 |
| 25 TED | −148.1 | 20.5 | −148.4 | 20.2 | −146.9 | 21.7 | −142.9 | 25.7 |
| | Typical | | Specified | | Typical | | Typical | |

Table 2. Video Threshold Points

Table 2 summarizes the results of bandwidth reduction video threshold tests. Some very significant conclusions can be drawn:

1. As the bandwidth becomes narrower the 1 dB departure point and the point of perceptible impulse noise on program material are farther apart. There would be even a greater difference had the S/N curves been made with no modulation on the main carrier (purely static S/N curves). This shows the importance of stating the point at which impulse noise is noted in addition to plotting a S/N curve.
2. Although color bars are a worst case subjective test for the occurrence of impulse noise there is infrequent programming that causes modulation approaching that due to color bars. Even though the results show the lowest C/T at which impulse noise becomes perceptible on programming with the 25 MHz filter, the appearance of impulse noise on a color bar test signal for the 25 MHz filter occurs at essentially the same C/T as with the 36 MHz filter. This is due to carrier amplitude reduction as the carrier moves to the skirts of the 25 MHz filter causing the carrier to be in an occasional threshold condition.
3. The audio thresholds for the 36 and 30 MHz case are similar. The curve for the 25 MHz case does not even come up to the theoretical asymptote. This was found to be due to severe video to audio crosstalk caused by distortions resulting from the severe bandwidth reduction. (Note that all audio S/N tests were conducted with a full field color bar video signal modulating the main carrier.) This further verifies the audible interference that was noted on the audio signal in the 25 MHz tests.

**Benefits of Using Threshold Extension**

Up to 3 dB of threshold improvement can be realized with a combination of the use of a 30 MHz filter and a threshold extension demodulator over a 36 MHz conventional receiver. In cases where insufficient margin above threshold is available using moderately priced LNA's (GaAs FET) with small aperture (5m) antennas the economics of the earth station quickly disappears if this margin above threshold has to be achieved with the use of a parametric amplifier or a significantly larger antenna.

Also, significant reductions of carrier level from the nominal operating level occur infrequently. However, the end user expects an acceptable picture during these periods so the added cost of the earth station by increasing the antenna size or adding a much more expensive LNA in some cases would be required for only infrequent signal degradations. If more than one carrier is received the margin above threshold is determined by the least powerful carrier. By using threshold extension a significant additional margin above threshold is provided and it can also be supplied to only those receivers carrying signals that normally have insufficient margin above threshold.

**Conclusions**

1. Threshold as defined simply by a 1 dB departure from the linear S/N assymptote can be a misleading and inaccurate measure of the subjective degradations on a video signal due to the appearance of impulse noise.
2. Reduction of the IF bandwidth from 36 to 30 MHz provides a 0.9 dB lower subjective threshold point at the expense of some moderate modulation truncation which does not manifest itself in significant video or audio distortions.
3. Threshold extension is available which allows operation at 2.0 dB lower C/T before the subjective threshold point is reached.
4. The INTELSAT type 25 MHz filter is too narrow to provide acceptable domestic video format reception.
5. To completely pass the domestic video modulation a 36 MHz filter is required.

**BIBLIOGRAPHY**

Beakley, G.W. and R.E. Flory. "Television by Satellite Experiment Conducted at Scientific-Atlanta." Princeton, N.J.: RCA David Sarnoff Research Center.

"Performance Characteristics of Earth Stations in the INTELSAT IV-A System." INTELSAT Document BG-11-40E, W/9/74, 20 September 1974.

Schwartz, Mischa. Information Transmission Modulation and Noise. McGraw-Hill Book Company, 1959.

Taub and Schilling. Principles of Communications Systems. McGraw-Hill Book Company, 1971.

# RECEIVERS and EXCITERS for FDM/FM MESSAGE

Written By:
Heinz Wegener
Edited By:
Edward J. Chapman
Manager, GCE Engineering
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## RECEIVERS AND EXCITERS FOR FDM/FM MESSAGE

### Introduction

Transmission of message (telephone conversations) via a geo-stationary satellite was first fully employed by the International Telecommunications Satellite Consortium (INTELSAT) managed by Communications Satellite Corporation (COMSAT). The first satellite (Early Bird later renamed INTELSAT 1) had a capacity of 240 telephone channels.[1] Since then several generations of satellites have been launched to provide worldwide telephone coverage via satellite through thousands of telephone channels. Although the initial interest was for international communications, recently more and more domestic message communications systems relayed via satellite have been built. In the U.S. the most notable application of message via satellite is the Alaskan system which utilizes the satellite to communicate within the state as well as to the rest of the U.S. Internationally, the Indonesian domestic satellite system was a very cost effective means of providing a communications link within the country. Since domestic satellite systems only have to provide coverage to a relatively small geographical area (as opposed to the global coverage provided by the INTELSAT network) the energy transmitted from the satellite can be more highly concentrated allowing a larger EIRP than from a satellite providing global coverage. This often allows the use of transmit and receive antennas in the 10 meter range for most domestic systems which provides further economic advantages.

In general an earth station that can transmit and receive video can also transmit and receive FDM/FM message signals.

The purpose of this paper is to briefly introduce the FDM/FM format used in satellite systems and explain requirements of the receivers and exciters used for message transmission and reception.

### The Basic Elements of a Message Transmit/Receive Station

Figure 1 is a block diagram of a message communications system. Essentially all equipment in a message earth station up to the multiplexing equipment is similar to the equipment in a video earth station. The operational requirements of the message exciters and receivers are quite similar in many respects to their video counterparts. In general, though, the technological requirements on a message receiver and exciter are more stringent to provide acceptable performance.

### General Message Transmission Information

Briefly discussed in the following is information particular to FDM/FM satellite message transmission.

### The FDM/FM Format

To understand mechanisms in a receiver or exciter that can degrade the message signal it is important to have a general concept of how the voice signals are combined to form the baseband signal that is injected into the exciter. In general the same techniques and equipment used to combine voice signals in a terrestrial microwave system are used in the satellite system.

1. M.J. Tant, "The White Noise Book", Printed in England by White Crescent Press Limited, Luton, July 1974, p. 19.

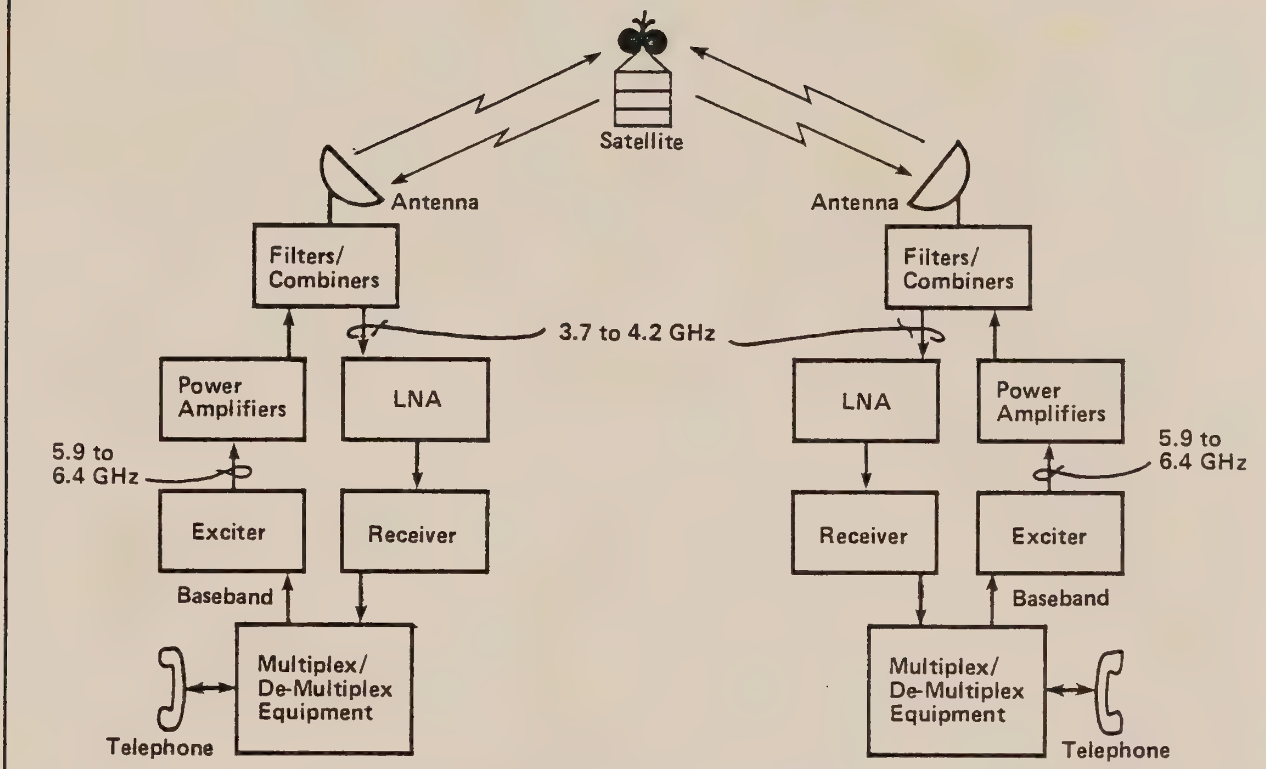



Figure 1 Message RX/TX Block Diagram

**Combining Voice Channels Into a Group** [2]

The concept of a group and how it is generated is fundamental to understanding how voice channels are combined. Each voice channel is frequency converted using single sideband suppressed carrier (SSBSC). Figure 2 shows a general block diagram of this process. Although 4 kHz is allotted for each voice channel, the voice signal is first filtered to only allow frequencies from 300 - 3400 Hz to pass. This allows some guard band in the final frequency multiplexing. The audio signal is then mixed with the carrier frequency ($f_1$) in a balanced modulator which provides attenuation of the carrier. The signal is then passed through a 4 kHz bandpass filter which further attenuates the carrier and also rejects the unwanted sideband. Usually the lower sideband is selected as shown in the block diagram. The symbol for the lower sideband in a single sideband suppressed carrier transmission as adopted by the CCITT is as shown in Figure 3.

The significance of the triangle is that if this signal ($f_1$ to $f_2$) is mixed with a frequency $f_2$ the output frequency decreases with an input signal increase in frequency.

2. Tant, pp 22-23.

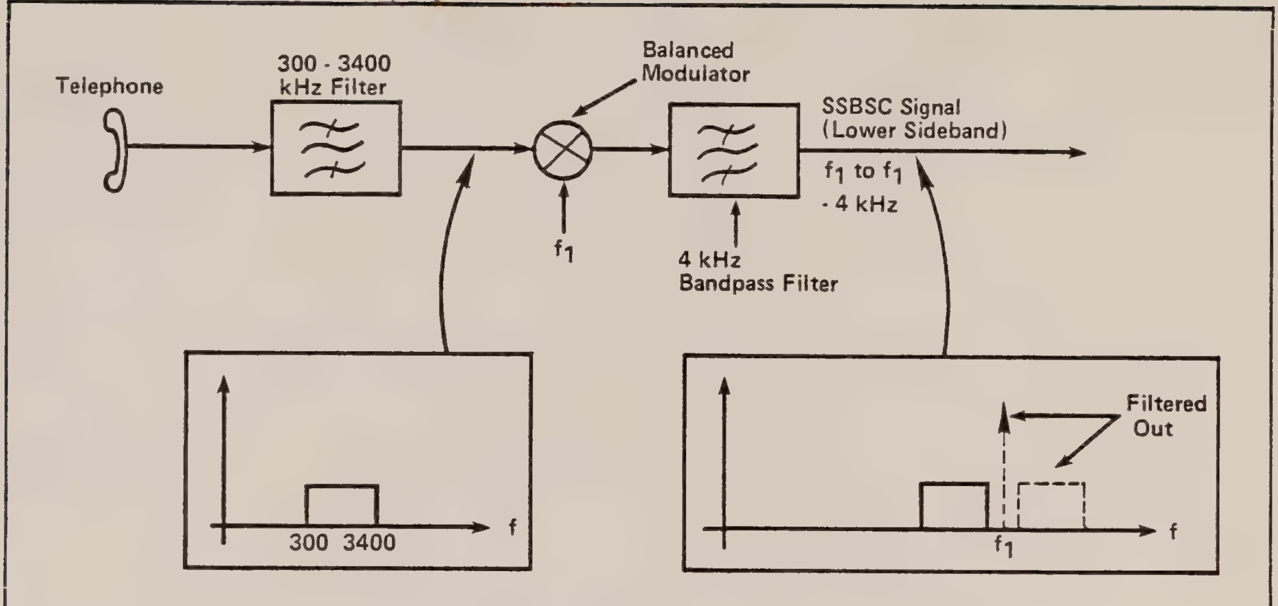



Figure 2. SSBSC Generation.

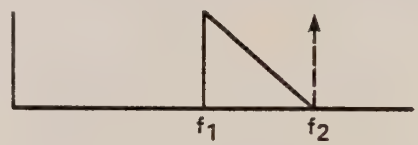



Figure 3. Symbol for Single Sideband, Suppressed Carrier (Lower Sideband Only Transmitted).

Carriers separated by 4 kHz in the 64 - 108 kHz band modulate 12 voice channels which then are summed together as shown in Figure 4 to form a group. The combining of channels is referred to as frequency division multiplexing (FDM). This group is called a Type B group in that channel 1 is at the highest carrier frequency and the output signal of any channel, if mixed with its carrier frequency would be inverted with respect to frequency (increase in input frequency equals decrease in demodulated frequency). In satellite transmission, a Type A group is typically also used. A Type A group is generated by beginning with a Type B group and mixing it with a 120 kHz signal to provide a 12 to 60 kHz group (120 - 108 kHz to 120 - 60 kHz). A type A group is usually used to take advantage of the 12 to 60 kHz baseband frequency range and as a basic block for further multiplexing.

The symbols for both types of groups are shown in Figure 5.

Conversion of the voice channels to a group is accomplished in what is called the channel translation equipment (CTE). All voice channels are first combined in a group which is the basic building block for further channel expansion.

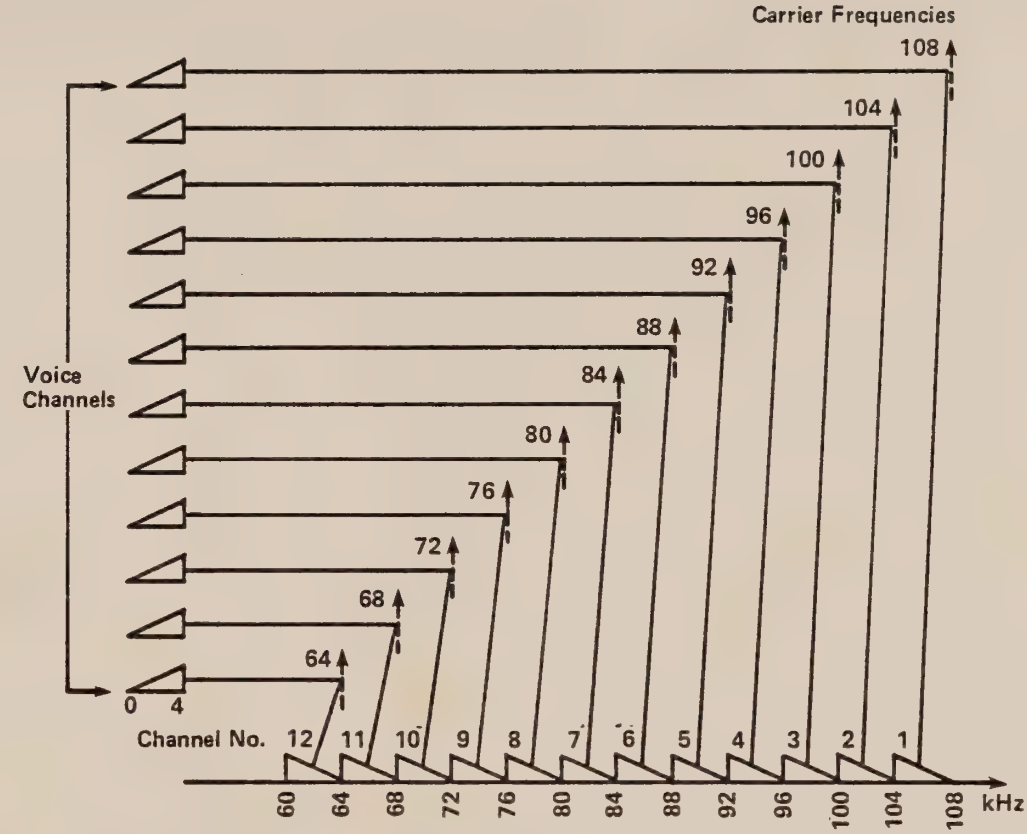



Figure 4. The Basic Group (Type B)

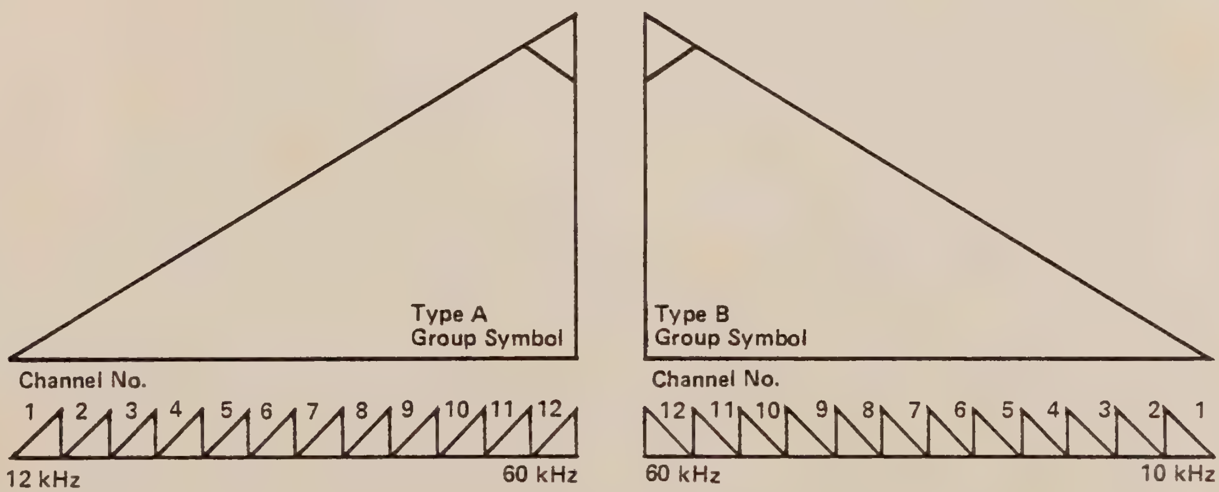



Figure 5. Symbols for Type A and Type B Groups.

**Super Groups** Again using the SSBSC technique entire groups are translated in frequency and combined to form super groups which are five groups translated in frequency as shown in Figure 6. Also, since frequency translation is accomplished using a frequency above the maximum frequency of the group, the super group is now erect with frequency.

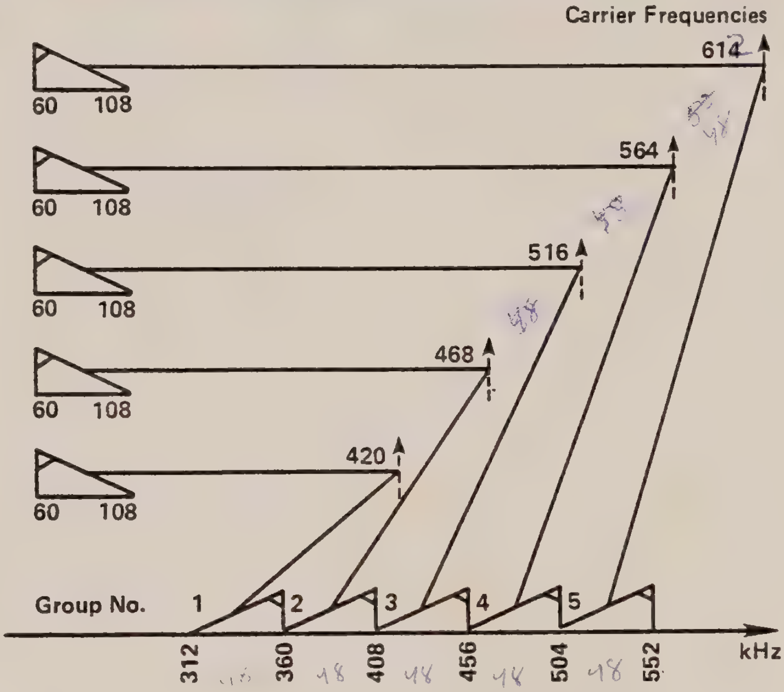



Figure 6. The Basic Supergroup.

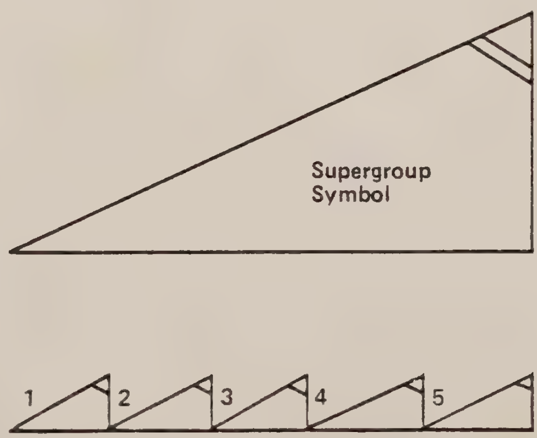



Figure 7. Supergroup Symbol

**Master Groups and Super Master Groups**

Super groups can be translated in frequency and combined to form the basic master group as shown in Figure 8. Additionally three basic master groups can be combined to form a super master group.

Typically in satellite transmission basic combinations above a super group are not used. Note that for the basic master group the super group numbers begin with 4 since it is possible to put 3 additional super groups below the first master group.

2044
812
1232

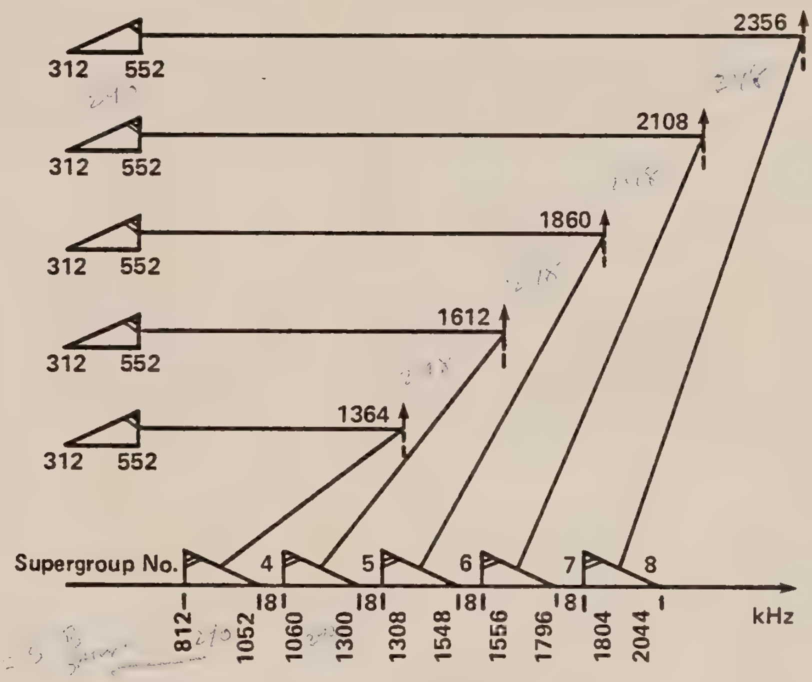



Figure 8. The Basic Mastergroup

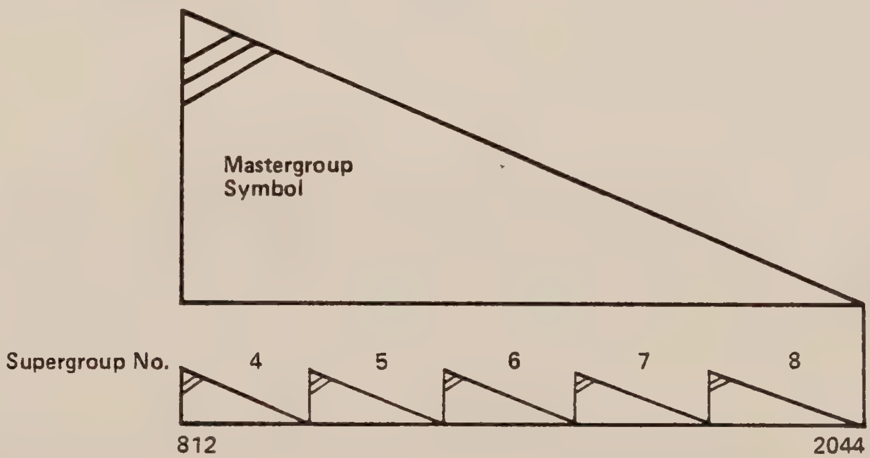



Figure 9. Master Group Symbol.

**The Purpose of "Grouping"**

Grouping in general allows economically efficient means of multiplexing and de-multiplexing voice channels. In addition, different geographical locations can be assigned certain groups for purposes of multi-destination co-ordination of the multiplexing plan.

**Pilots**

Not shown in the group symbols are pilots which are highly stable frequencies used as references to accurately multiplex or de-multiplex the various groups. This "mux synchronization" allows accurate reproduction of the transmitted voice channel.

Another type of pilot is a baseband continuity pilot which is used to detect if a failure has occured in any baseband signal processing circuitry. In satellite transmission this pilot is often chosen to be at 60 kHz so that one frequency can be used as a continuity pilot for virtually all channel capacities.

**Typical Satellite Message Baseband Format**

Figure 10 shows the arrangement of a baseband message format which is typical. The frequency range below 4 kHz is usually used for the energy dispersal waveform (triangular waveform used to keep the radiated flux density below a certain maximum level) and its associated harmonics. The 4 to 12 kHz band is used as an engineering service band. The 12 kHz to 60 kHz band is occupied by a Type A group and above 60 kHz can be occupied by a Type B group (for 24 channels) to combinations of groups, super groups, master groups, etc., depending on the total channel capacity of the system.

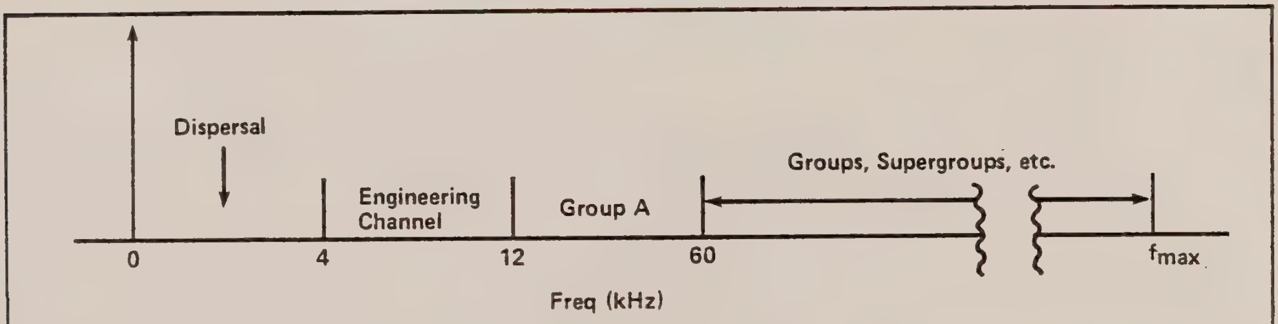



Figure 10. Baseband Arrangement of Satellite Message Format.

**Channel Capacity versus IF Bandwidth**

Although the top baseband frequency is directly a function of the channel capacity there is some flexibility in selecting the deviation of the modulated signal. The larger the deviation, the better the FM improvement. Therefore the IF bandwidth required to transmit a message signal depends on:

1. Available EIRP from the satellite.
2. Gain-to-Noise temperature (G/T) of the receive earth station.
3. Desired operating signal-to-noise ratio of the voice channel.

Table 1 lists some typical IF bandwidths for various channel capacities as specified by INTELSAT[3]. In the list note, for instance, the two 72 channel IF bandwidths that can be used are 2.5 MHz and 5.0 MHz. The "RMS MC Devia (kHz)" column which is the multi channel deviation of the carrier with all voice channels used goes from 261 kHz RMS to 616 kHz RMS when going from 2.5 MHz to 5.0 MHz respectively. The "8000 + 200 pWp0 C/T" column which is an indication of relative carrier EIRP required from the satellite to the same earth station to maintain an equal S/N ratio in the voice channel shows that 7.4 dB less (−149.1 vs. −141.7 dBW/° K C/T) signal

3. "Performance Characteristics of Earth Stations in the INTELSAT IV-A System", BG-11-40E, W/9/74, 20 September 1974, pp 48-49.

power is required if 5.0 MHz is used as the IF bandwidth for 72 channels instead of 2.5 MHz.* Or, conversely, with the same EIRP, the earth station could have a lower G/T to maintain an equivalent performance which might mean use of a much smaller antenna or higher noise temperature LNA both of which suggest lower station cost. In the INTELSAT system the differences in bandwidths are due in general to variations in EIRP due to different sized geographical coverage of the transmitted signal.

| Channel** Capacity | BW (MHz) | Top BB Freq (kHz) | RMS MC Devia. (kHz) | 8000 + 200 PwPo C/T (dBW/°K) |
|---|---|---|---|---|
| Intelsat | | | | |
| **12 | 1.25 | 60 | 159 | −154.7 |
| 24 | 2.5 | 108 | 275 | −153.0 |
| 36 | 2.5 | 156 | 307 | −150.0 |
| 48 | 2.5 | 204 | 275 | −146.7 |
| 60 | 2.5 | 252 | 276 | −144.0 |
| 60 | 5.0 | 252 | 546 | −149.9 |
| 72 | 2.5 | 300 | 261 | −141.7 |
| 72 | 5.0 | 300 | 616 | −149.1 |
| 96 | 5.0 | 408 | 584 | −145.5 |
| 96 | 7.5 | 408 | 799 | −148.2 |
| 132 | 5.0 | 552 | 529 | −141.4 |
| 132 | 7.5 | 552 | 891 | −145.9 |
| 132 | 10.0 | 552 | 1020 | −147.1 |
| 192 | 5.0 | 804 | 459 | −136.3 |
| 192 | 7.5 | 804 | 758 | −140.6 |
| 192 | 10.0 | 804 | 1167 | −144.4 |
| 252 | 7.5 | 1052 | 733 | −137.1 |
| 252 | 10 | 1052 | 1009 | −139.9 |
| 252 | 15 | 1052 | 1627 | −144.1 |
| 312 | 10 | 1300 | 1005 | −137.1 |
| 312 | 15 | 1300 | 1716 | −141.7 |
| 432 | 15 | 1796 | 1479 | −136.2 |
| 432 | 17.5 | 1796 | 1919 | −138.5 |
| 432 | 20 | 1796 | 2276 | −139.9 |
| 432 | 25 | 1796 | 2688 | −141.4 |
| 612 | 20 | 2540 | 1996 | −134.2 |
| 792 | 20 | 3284 | 1784 | −129.9 |
| 792 | 25 | 3284 | 2494 | −132.8 |
| 972 | 25 | 4028 | 2274 | −129.4 |
| 972 | 36 | 4028 | 4417 | −135.2 |
| 1092 | 36 | 4892 | 4118 | −132.4 |
| 1332 | 36 | 5684 | 3834 | −129.3 |

* The values shown are theoretical in actual use, noise performance is usually specified to be within 1 dB of the noted values.
** In the INTELSAT V system (BG28-72E) a 12 channel carrier has been added.

Table 1. Message Formats

**Transponder Utilization**

As Figure 11 shows a transponder can be divided up into many different ways. [4] Division of transponder space depends on several factors. The major factor is population density and use of telephone circuits in an area. It must be remembered that transmission of each carrier occurs at one site while reception of the signal can occur anywhere in the acceptable signal level pattern of the satellite. Therefore transmission from a major metropolitan area like New York City might be via a 972 channel or larger carrier. Any station can then pick off a voice channel from this carrier. However, to provide the return conversation from a small midwestern hamlet might be accomplished through a 24 channel carrier. As Figure 11 shows, in general, the most cost effective arrangement in terms of total channels per MHz of transponder space is with the large channel carriers. Also in regard to transponder carrier allocation note that for 2 or more, carriers to be transmitted in a transponder requires a reduction in uplink transmitted power to avoid intermodulation between carriers which would occur if the transponder was saturated. In general, the more carriers there are in a 40 MHz transponder, the lower the EIRP of each carrier due to this "back-off" in power.

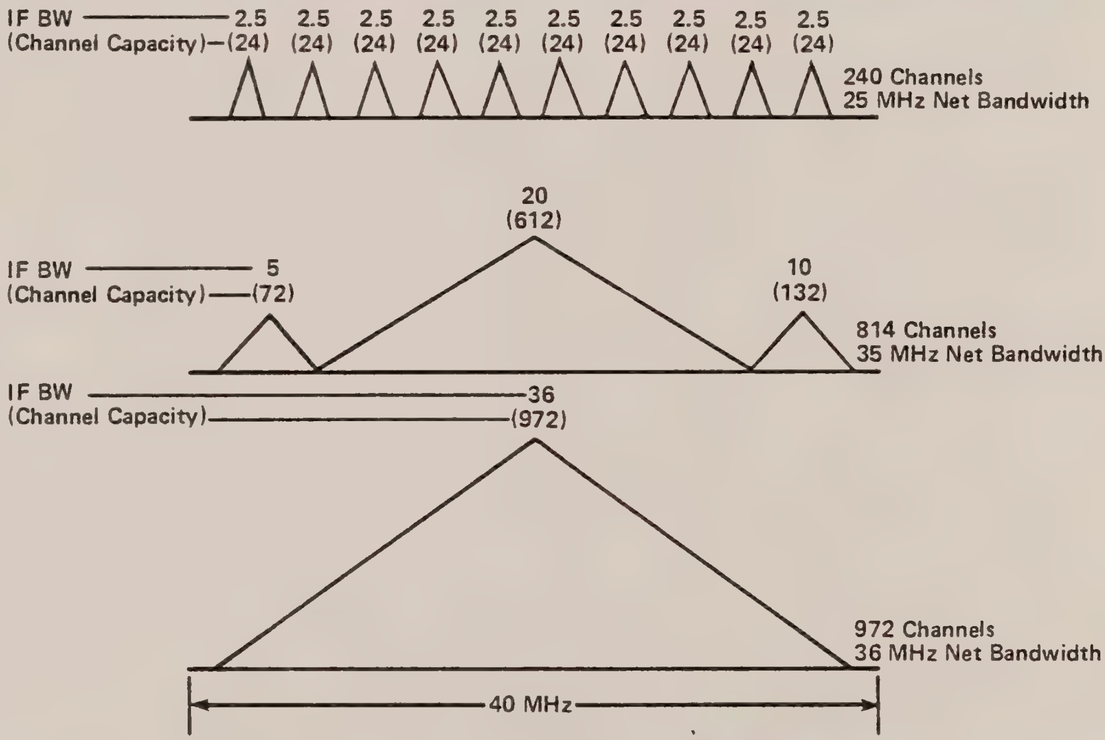



Figure 11. Various Transponder Carrier Allocations.

**Satellite Transmission Time Delay**

Since the transmitted signal travels over 44,000 miles before it reaches the receive station in a satellite system there is a much greater total delay of the voice signal from speaker to listener when compared to a coast-to-coast terrestrial transmission where the signal travels 3000 miles. This delay is not objectionable for a single satellite hop but if the signal goes through two satellites the time delay is on the order of 0.5 sec and becomes moderately annoying.

4. Burton I. Edelson, "Global Satellite Communications", Scientific-American, Feb., 1977, p. 68.

**Simulation of the FDM Format**

Once the voice channels and groups are combined the composite baseband signal is injected into the exciter. To determine what degradations are provided by any equipment after the FDM signal leaves the multiplexing equipment and before it enters the de-multiplexing equipment requires a method of simulating the FDM baseband signal. It has been shown that the characteristics of a fully loaded (all voice channels used) FDM signal can be simulated by white noise (flat power versus frequency spectrum and gausian distribution of amplitude) whose bandwidth is restricted to include only the frequency range of the channel capacity tested.[5]

This is the basis for the noise load test set which is the common test set used for evaluation of all FDM degradations which occur external to the multiplex equipment. Simulation of the FDM format using a white noise source can be seen to be intuitively correct by recalling the generation of the 12 channel group. Each channel consists of a signal whose amplitude and frequency vary with speech volume and frequency respectively. For large channels and a large variation of speakers, a totally random frequency spectrum with amplitude variations tending to average to the volume of a typical speaker would appear on a spectrum analyzer for a fully loaded transmission.

**Mechanisms of Distortions and Principles of White Noise Testing.**

The SSBSC–FDM format can be generally equated to addition of discrete frequencies. The prime cause of distortion in a multi-carrier system is intermodulation products which occur when the carriers mix with each other and generate sum and difference frequencies that "spill" into other channels.

Distortions due to intermodulation products in the message format generally appear as random interference or noise since these products are not related to the frequency interfered with.[6]

In an exciter or receiver there are several non-linear mechanisms that create intermodulation products. Measuring the degration due to intermodulation is accomplished using the white noise test set.

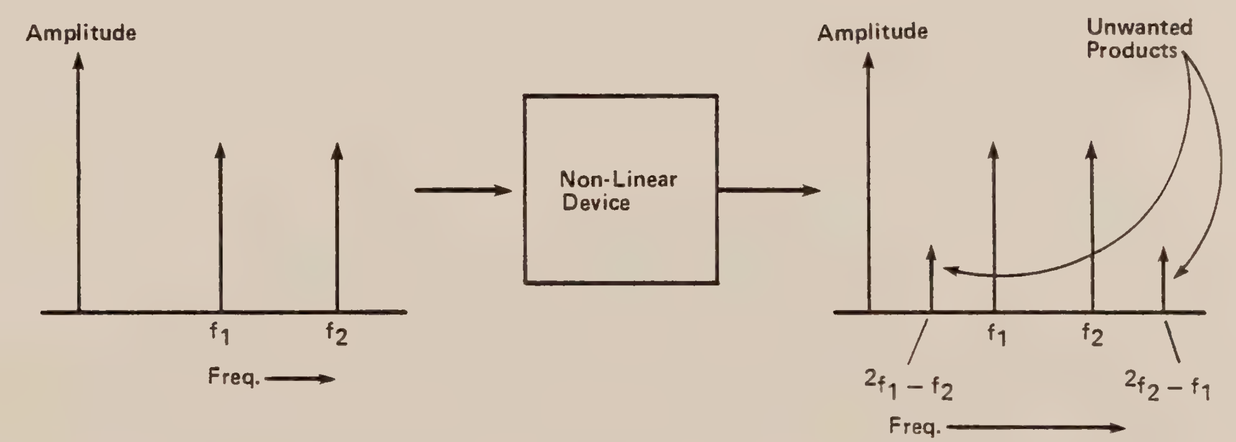



Figure 12. Third Order Intermodulation Products

5. Tant, p. 50.
6. Ibid, p. 43.

**NPR and BINR Measurements**

Figure 13 shows the general technique used to measure degradations due to intermodulation.[7]

A. First a white noise spectrum bandlimited in accordance within the frequencies ($f_1$ to $f_2$) of the channel capacity tested is injected at the proper level into the item under test by the noise generator.

B. The power level ($P_1$) of the noise at the frequency intermodulation distortion is to be measured ($f_3$) is then measured on the noise receiver. Note that the spectrum out of the item under test is shown to be flat which is not always the case.

C. After the reference level has been noted on the receiver, a bandstop filter is inserted in the noise generator creating a "clean" channel.

D. The new power level measured in the receiver at $f_3$ ($P_2$) is a result of intermodulation products which have "filled in" the previously clean slot so the ratio of $P_1$ to $P_2$ is a direct indication of degradations in the channel slot due to intermodulation in the item under test. The decibel ratio of the noise level with all channels occupied to the noise level with all channels but the measurement channel occupied is called the noise power ratio (NPR).[8]

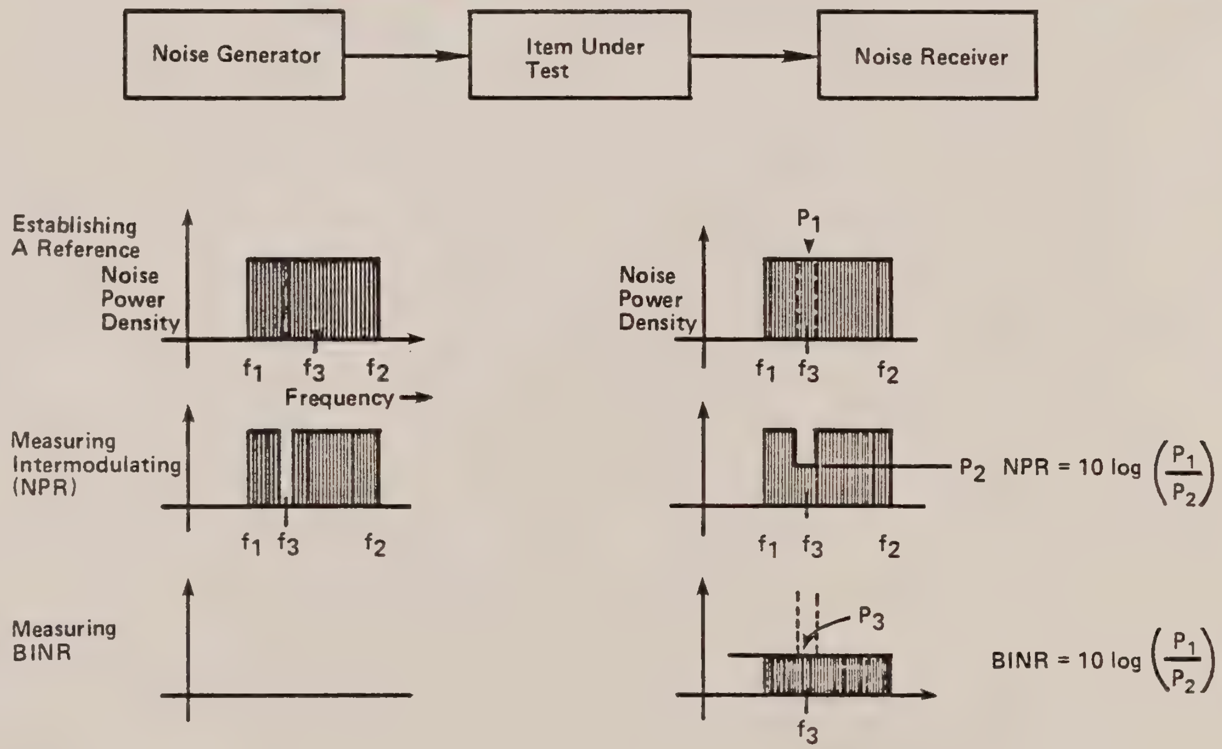



Figure 13. Measurement of NPR and BINR.

Another useful measurement is the basic intrinsic noise ratio (BINR) which uses the same reference power ($P_1$) as for NPR. BINR is a measure of the best that can be achieved in the item under test due to the intrinsic noise "floor" of the device.

7. Tant, p. 52.
8. Ibid, p. 52.

It is measured by removing the white noise signal from the generator and measuring the power level ($P_3$) in the channel slot ($f_3$) under test. BINR is then the ratio of $P_1$ to $P_3$ expressed in logrithmic terms.

If the NPR is much greater than the thermal noise floor a measure of S/N ratio in channel slots can also be determined by making the NPR measurement and recognizing that the intermodulation level is well below the level measured for $P_2$.

To provide consistency in NPR measurements recommendations have been made on the bandwidth of the bandstop filters (and the bandpass filters in the receivers) by the CCIR and CCITT [9] which have been adopted by most manufacturers of noise load equipment. Also controlled by these recommendations are the characteristics of the high pass and low pass filters which provide the band limiting of the white noise spectrum according to the channel capacity tested.

To be most thorough each channel would have to be measured. This would be a time consuming process even for a 24 channel format. In general, conclusive results can be determined by measuring NPR's in a few slots which is the test technique that is universally accepted. The noise slot frequencies are standardized by the CCIR and CCITT and generally a total of three to five slots are measured at the low, mid, and high end of the baseband frequency range for the channel capacity tested.

**Message Exciters and Receivers**

Now that some fundamental aspects of message systems have been covered a description of the message exciters and receivers used in an earth station will be covered. A discussion of important specifications and how they relate to degradations will follow the hardware description.

## EXCITER

**Purpose of the Message Exciter**

The purpose of the exciter is to process the baseband format of Figure 10, (by providing low pass filtering, pre-emphasis, and injection of the energy dispersal waveform), FM modulate a carrier with the processed baseband, and convert the carrier frequency to the 5.925 to 6.425 transmit frequency band.

GH3

**Block Diagram Discussion**

A general block diagram of a message exciter is shown in Figure 14. The baseband signal is first pre-emphasized. Pre-emphasis is simply shaping the frequency response of the baseband signal. Most message systems use the pre-emphasis curve of CCIR recommendation 275-1 (Figure 15) which causes the highest baseband frequency component to be about 8 dB larger in amplitude than the lowest frequency (assuming the frequency response of the signal injected into the pre-emphasis network was flat). The attenuation characteristics are referenced to the "crossover" frequency (0.608XF max). Pre-Emphasis is usually used to improve the signal-to-noise(S/N) ratio in an FM system by correcting for the triangular noise which occurs during FM demodulation (Figure 16).

9. Tant, pp 64-71.

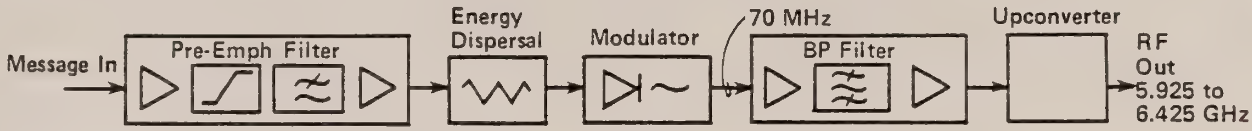



Figure 14. Message Exciter Block Diagram.

Equation of the Curve

$$dB = 5 - 10\log_{10}\left[1 + \frac{6.9}{1 + \frac{5.25}{\left(\frac{5f_{max}}{4f} - \frac{4f}{5f_{max}}\right)^2}}\right]$$

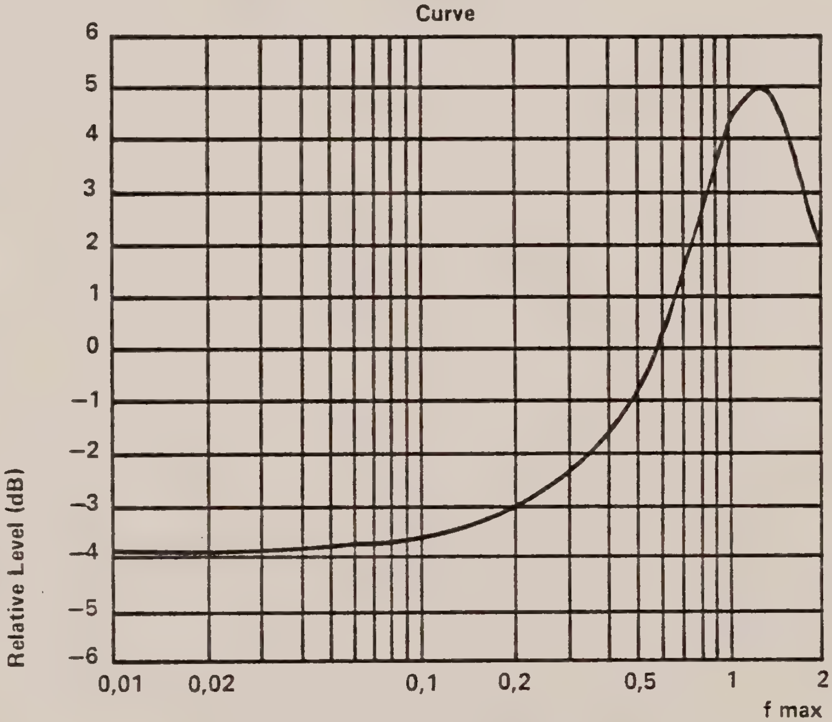



Figure 15. Pre-Emphasis Curve
to CCIR Recommendation 275-1.

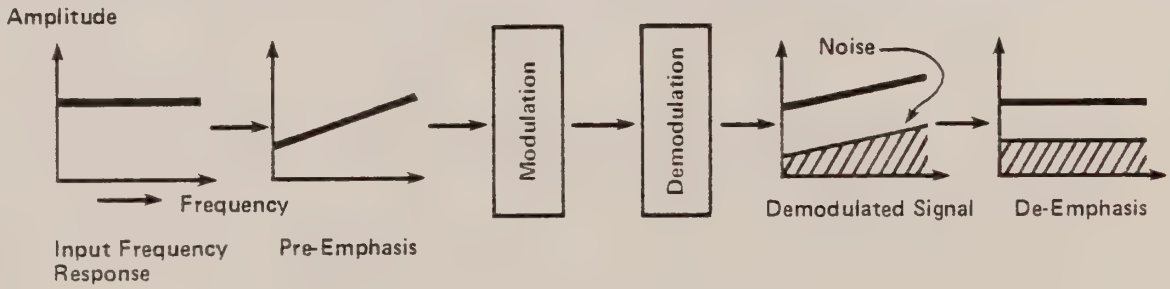



Figure 16. Pre- and De-Emphasis Effect On
Triangular Demodulation Noise

**Roofing Filter** After being pre-emphasized the baseband signal is passed through the roofing filter which provides low pass filtering of the baseband signal and also establishes a "clean" frequency notch above the highest baseband frequency. This notch provides a means of determining the receive signal-to-noise ratio of the baseband by monitoring how much thermal noise (or in cases of severe distortion how much intermodulation) has filled in this slot with an out-of-band noise (OBN) detector. This is essentially the same technique as measuring NPR's which was discussed earlier. The OBN notch is centered at typically 7 to 10 percent above the top frequency and has at least a 50 dB notch over a band of $\pm(0.005\ f_c + 2)$ kHz where $f_c$ is the notch center frequency [10]. Center frequencies of notches for various channel capacities for the INTELSAT system are shown in Table 2 [11].

| Baseband Capacity (Channels | Center Frequency ($f_c$) (kHz) |
|---|---|
| 24 | 116 |
| 36 | 172 |
| 60 | 277 |
| 72 | 331 |
| 96 | 448 |
| 132 | 607 |
| 192 | 884 |
| 252 | 1157 |
| 312 | 1499 |
| 432 | 1976 |
| 612 | 2794 |
| 792 | 3612 |
| 972 | 4430 |
| 1092 | 5381 |
| 1332 | 6300 |

Table 2. Center Frequency of Noise-Measuring Bands for INTELSAT.

**Energy Dispersal Addition** After the signal has been pre-emphasized and passed through the roofing filter the energy dispersal waveform is added to the baseband signal. The energy dispersal waveform is simply a triangular waveform with a frequency of 20 to 150 Hz [12]. This triangular waveform provides dispersion of energy by modulating the carrier when there are few or no active voice channels in the baseband to modulate the carrier. The dispersal waveform reduces the radiated power at any one RF frequency to below a maximum level which reduces interference with terrestrial networks and other satellite systems.

Generation of the dispersal waveform for message is more difficult than for video in that in the absence of any active voice channels the modulation of the carrier by the baseband drops to nearly zero. On the other hand, for a fully loaded message baseband, the carrier is deviated properly to not require any dispersal. In fact, dispersal on a fully loaded baseband would provide a waste of satellite frequency space. Therefore the message dispersal level is usually inversely proportional to the channel loading (i.e., no dispersal for full channel loading; full dispersal for no channel loading). Figure 17 illustrates this proportional dispersal addition.

Since speech usually is combinations of short bursts of conversation followed by various pauses and relatively long quiet moments where the speaker listens to whom he is talking the reaction time of the dispersal level to changes in baseband levels must be relatively slow (especially for low channel capacity formats). Typically some limiting of the baseband signal is also provided (usually for up to a 10 dB larger baseband signal level than normal) prior

10. "Performance Characteristics of Earth Stations in the INTELSAT IV-A System", p. 82.
11. IBID, p. 82.
12. IBID, p. 39.

to injection in the modulator. This is sometimes accomplished in the energy dispersal section and the purpose is to contain modulation within allocated IF bandwidths despite momentary increases in baseband levels due to a large number of "loud" talkers speaking simultaneously.

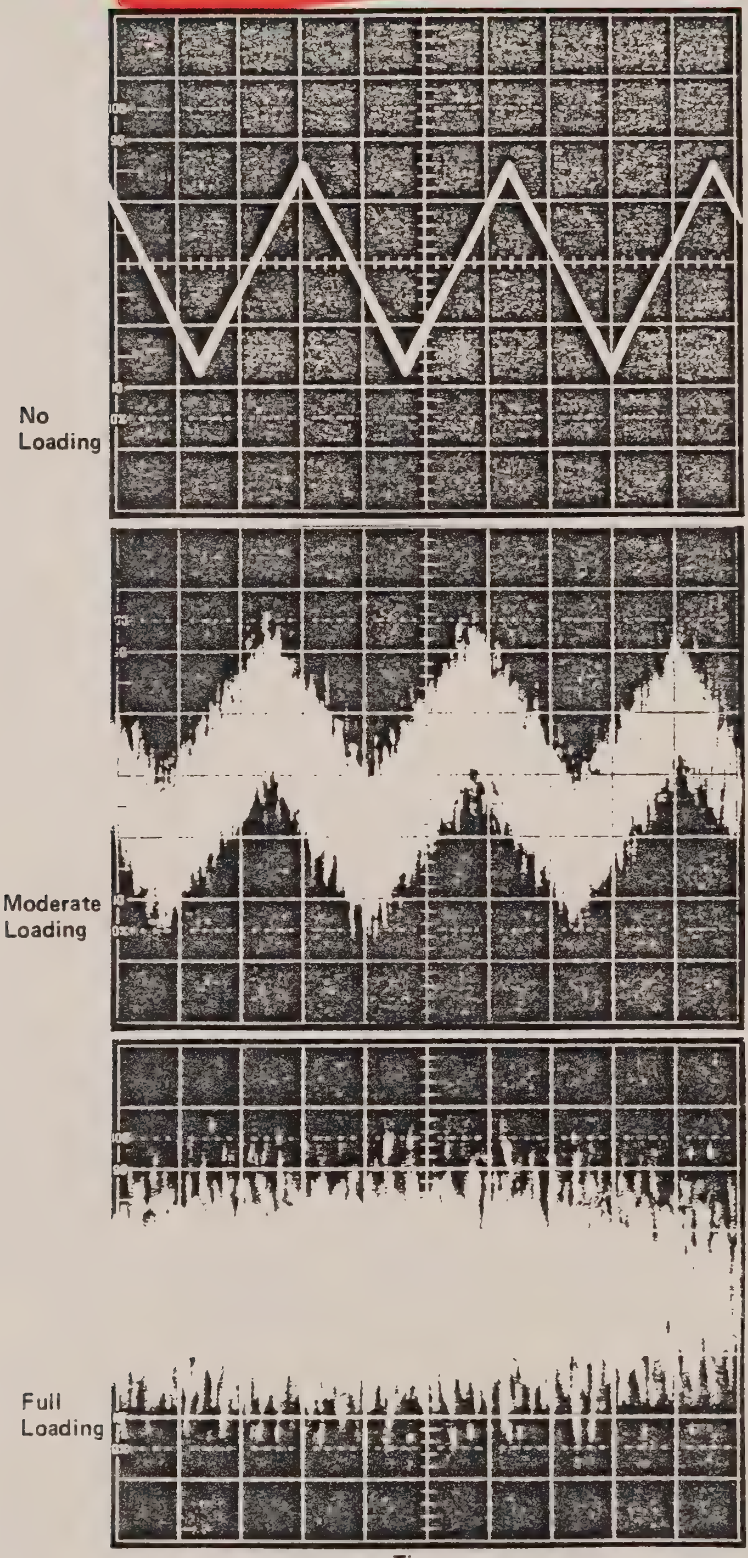



Figure 17. Proportional Energy Dispersal Waveform Generation.

**FM Modulation** The composite baseband is next injected into a wideband (capable of providing low distortion modulation for up to ±18 MHz deviation) modulator. It is this process where the FM in the FDM FM notation is applied (actually a more accurate abbreviation for the message format might be SSBSC - FDM - FM). The output of the modulator is the carrier. Further operations on the carrier merely translate the center frequency to the proper RF frequency.

**IF Filter** The modulated carrier is next injected into an IF filter which is included mainly to keep modulator over-deviation or a drastic center frequency change from spilling energy into an adjacent satellite band.

**Upconverter** The upconverter translates the 70 MHz carrier to the 5.925 to 6.425 GHz band. Typically some form of automatic leveling is provided to provide a very stable output power over a long period of time.

**Additional Equipment** Occasionally other operations are performed either physically in the exciter or external to it but in the exciter signal path.

**Pilot Generation** Although the continuity pilot (usually at 60 kHz) is usually generated in the multiplex equipment it will occasionally be combined with the multiplexed signal in the exciter.

**Delay Equalization** Although generally the exciter is properly delay equalized frequently an adjustable delay equalizer will be inserted at 70 MHz for equalization of the 6 GHz power amplifiers and the satellite.

**Alarming** Monitoring key parameters and providing an alarm signal for out of tolerance conditions is generally provided in the exciter.

## RECEIVER

**Purpose of the Message Receiver** The purpose of the receiver is to select the proper carrier, downconvert it to an intermediate frequency, demodulate the carrier, and provide proper baseband processing to restore the multiplexed signal to its original form when it was injected into the exciter.

**Block Diagram Discussion** A general block diagram of the message receiver is shown in Figure 18.

**Downconverter** The 3.7 to 4.2 GHz signal is converted to a 70 MHz IF frequency in the downconverter. Downconversion is usually accomplished using dual conversion so that the desired carrier can be selected by providing the proper first local oscillator (LO) frequency.

**IF Filter** This unit determines the pre-detection bandwidth which must be of proper size for the carrier selected.

**AGC Amplifier** This unit provides automatic gain control (AGC) to keep the signal level into the demodulator constant if the RF level of the carrier into the receiver changes.

**Demodulator** The demodulator provides limiting of the incoming signal to remove unwanted amplitude modulation (AM) on the carrier. The signal is next demodulated in a wide band (±18 MHz), highly linear discriminator.

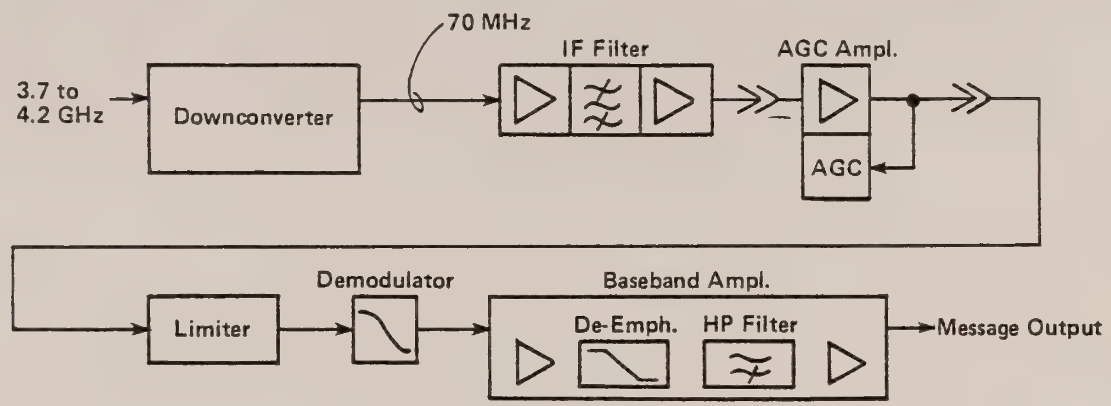



Figure 18. Message Receiver Block Diagram.

**Baseband Amplifier** Typically the baseband processing to convert the demodulated signal back to the form in which it was injected into the exciter is performed here. Provided is de-emphasis to restore the flat frequency response of the signal through a de-emphasis network whose frequency response is the complement of the pre-emphasis network in the exciter. In addition, a 4 kHz high pass filter removes the energy dispersal waveform and its associated harmonics.

**Additional Equipment**

**Pilot/Noise Detector** The purpose of this unit is to detect the continuity pilot and monitor the noise level of the out of band noise (OBN) slot to determine if the S/N of the received baseband signal allows sufficient voice channel quality.

**Baseband Squelch** Occasionally it is desired to mute the composite baseband signal in the event of a receiver or carrier failure.

**Threshold Extension Unit** Occasionally the operating C/T (Carrier power/system noise temperature) is relatively close to the point at which a conventional demodulation thresholds. The subjective effect on a voice channel when the demodulator operates at or below its threshold point is audible clicks. Various techniques are used to extend the threshold point below that of a conventional demodulator.

**Receiver Alarm Module** This unit monitors various receiver parameters and provides an alarm signal upon detection of an out-of-tolerance parameter.

**Important Message Receiver and Exciter Technical Characteristics** The measurement that indicates acceptable receiver or exciter performance is the NPR test as discussed earlier. This test provides an indication of both intermodulation degradations due to equipment induced distortions and voice channel S/N performance at various carrier-to-noise power density ratios. The following discussion of important technical characteristics will in general provide the end object of acceptable NPR performance.

**Baseband Requirements** Although often not specified individually all baseband amplification must be extremely linear, any amplifier operating close to saturation will cause excessive harmonic distortion and intermodulation of the FDM multiplexed signal.

**Modulator and Demodulator Linearity** Linearity is a measure of the accuracy of the transfer function of the modulator (MHz/volts) and the demodulator (volts/MHz) over the deviation range. To minimize message distortions this accuracy (linearity) must be within 1% on any portion of the deviation range for the modulator and demodulator. Non linearity causes harmonic distortion of the baseband. Non linearity also causes differential gain which is defined as follows:[13]

**Differential Gain** — The difference in gain encountered by a low level, high frequency sinusoid at two stated instantaneous amplitudes of a superimposed low-frequency signal. Differential gain is a measure of the intermodulation at two specific frequencies and is used to predict noise load performance of high channel capacity systems.

**RF and IF Gain Flatness** Non flatness across the modulated carrier bandwidth (at either RF or IF frequencies) causes it to become amplitude modulated. Most of the AM is usually removed in a limiter preceding the demodulator. However, practical limiters are highly non-linear devices and (particularly in cases of severe amplitude non-flatness) produce some AM to FM conversion. The effect of AM to FM conversion on the demodulated signal is the generation of harmonics and intermodulation products. To allow acceptable message performance, the RF to IF flatness of either an exciter or a receiver should fall within the masks as recommended by INTELSAT shown in Figure 19.

**RF and IF Phase Linearity** Phase linearity is commonly discussed in terms of group delay which is defined as the derivative of the phase/frequency response. The group delay limits of the exciter and receiver should meet the requirements of the mask of Figure 19. Non-linear phase results from conventional filtering and must be equalized to provide a group delay characteristic which falls within the mask of Figure 19 to yield satisfactory performance. Group delay distortions cause the following degradations of the demodulated signal.

1. Baseband gain/frequency variations.
2. Harmonic distortion.
3. Baseband intermodulation.
4. Differential phase distortions.

Differential Phase is defined as follows:[14]

**Differential Phase** — The difference in phase shift encountered by a low-level high frequency sinusoid at two stated instantaneous amplitudes of a superimposed low-frequency signal.

Differential Phase is a measure of the intermodulation at two specific frequencies and is used to predict noise load performance of high channel capacity systems.

**RF and IF Return Loss** Return loss is a measure of the impedance match at signal interfaces. Poor return loss can result in group delay ripples which will lead to the same distortions mentioned in the phase linearity section. A return loss of at least 20 dB (VSWR @1.22:1) should be maintained at any RF port and a return loss of 23 to 26 dB should be maintained at all IF interfaces.

13. "Transmission Distortions", Hewlett-Packard Application Note, July 1973, p. 49.
14. IBID, p. 47.

**Demodulator Threshold Performance**

Demodulator threshold is defined as that C/N at which the S/N ratio (or NPR) deviates from the linear theoretical assymptote by 1 dB. In a message system, channels in the low frequency end of the baseband frequency band threshold before the channels at the high end of the baseband frequency range. The effect on the voice channel is the appearance of audible clicks. Threshold extension techniques are occassionally used to allow operation at a lower C/N before threshold occurs.

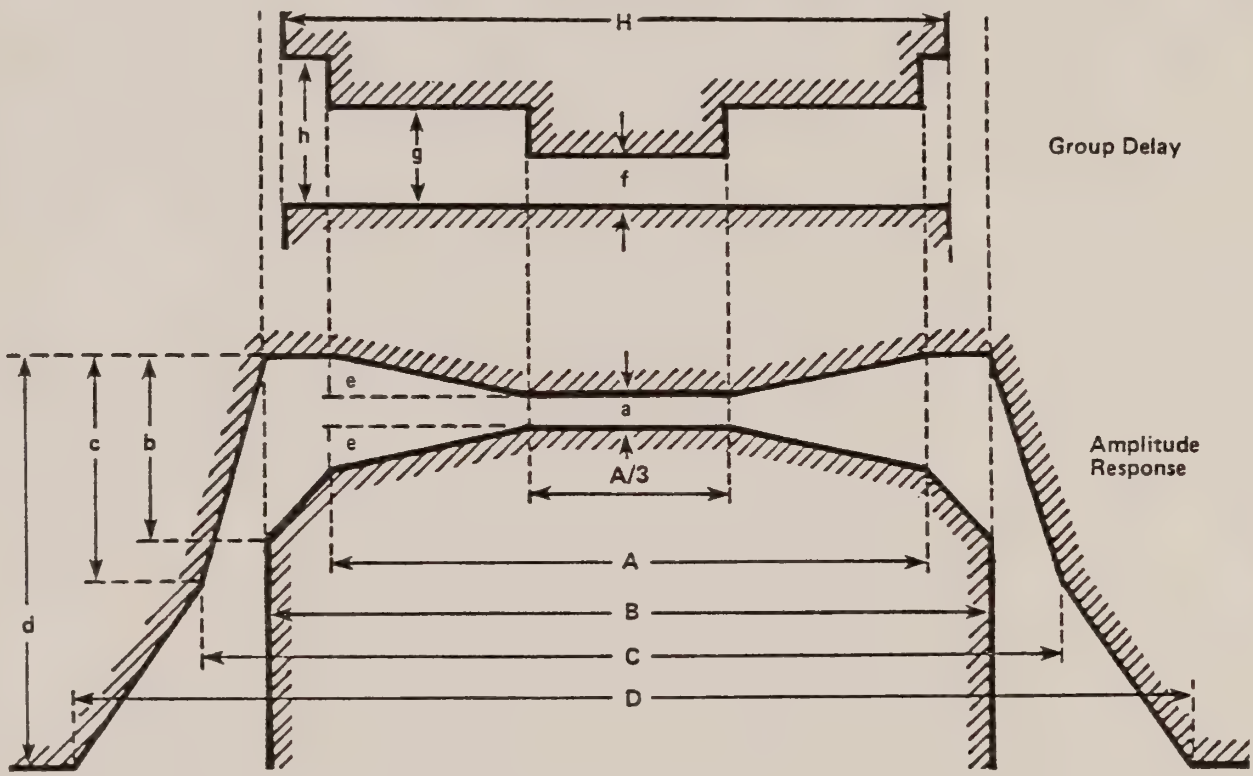



Figure 19A. Receiver/Exciter.

| S-A Part No | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131621 | 2.5 | 1.8 | 2.25 | 2.75 | 8.0 | 0.7 | 1.5 | 2.5 | 25 | 0 | 2.1 | 16 | 16 | 20 |
| 131622 | 5 | 3.6 | 4.5 | 5.25 | 13.0 | 0.5 | 2.0 | 3.0 | 25 | 0 | 4.1 | 12 | 12 | 20 |
| 131623 | 7.5 | 5.4 | 6.75 | 7.75 | 17.0 | 0.4 | 2.5 | 4.0 | 25 | 0 | 6.2 | 12 | 12 | 20 |
| 131624 | 10 | 7.2 | 9.0 | 10.25 | 19.0 | 0.3 | 2.5 | 5.0 | 25 | 0.1 | 8.3 | 9 | 9 | 18 |

| S-A Part No. | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131625 | 15 | 10.8 | 13.5 | 15.5 | 25.0 | 0.3 | 2.5 | 5.5 | 25 | 0.1 | 12.4 | 6 | 6 | 15 |
| 131626 | 17.5 | 12.6 | 15.75 | 18 | 26.5 | 0.3 | 2.5 | 6.5 | 25 | 0.1 | 14.2 | 6 | 6 | 15 |
| 131627 | 20 | 14.4 | 18.0 | 20.5 | 28.0 | 0.3 | 2.5 | 7.5 | 25 | 0.1 | 16.6 | 4 | 5 | 15 |
| 131628 | 25 | 18.0 | 22.5 | 25.75 | 34.0 | 0.3 | 2.5 | 8.0 | 25 | 0.2 | 20.7 | 3 | 5 | 15 |
| 131930 | 36.0 | 28.8 | 36.0 | 45.25 | 60.0 | 0.6 | 2.5 | 10.0 | 25 | 0.3 | 33.1 | 3 | 5 | 15 |
| 131929 | 30 (video) | 24.0 | 30.0 | – | – | 0.5 | 2.5 | – | – | 0.3 | 30.0 | 5 | 5 | 15 |

Figure 19B. Receiver/Exciter Amplitude-Delay Characteristics.

BIBLIOGRAPHY

1. Edelson, Burton I., "Global Satellite Communications", Scientific American, Feb., 1977, pp 58-73.
2. "Performance Characteristics of Earth Stations in the INTELSAT IV—A System", Document No. BG-11-40E, W/9/74, September 20, 1974.
3. Tant, M.J., The White Noise Book, Printed in England by White Crescent Press Limited, Luton, England, First Printing July, 1974.
4. "Transmission Distortions", Hewlett-Packard Application Note, July, 1973.

## APPENDIX A

**Scientific-Atlanta Series 461 Message Exciter**

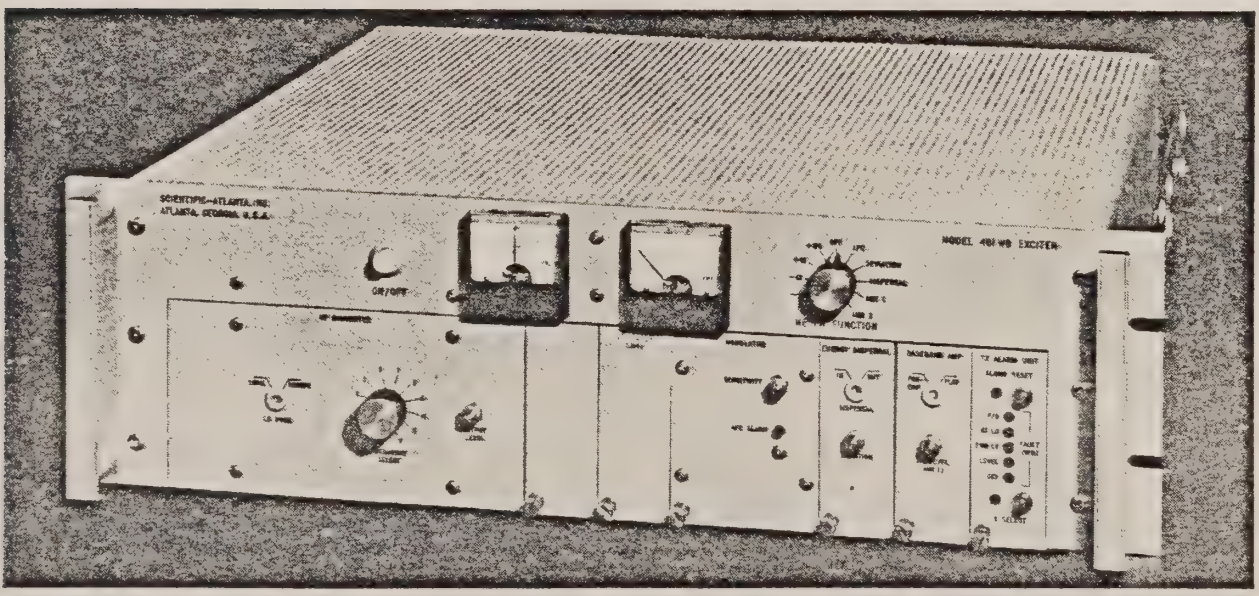
Scientific-Atlanta's Series 461 Message Exciters are integrated modulator/upconverter units. Baseband and modulator sections are designed as plug-in modules to the dual-conversion upconverter chassis. This fully interchangeable plug-in modular construction results in simplified maintenance and repair, and built-in monitoring and test facilities permit rapid status evaluation. Photograph 6741 shows a typical Series 461 Message Exciter equipped with transmit alarm, energy dispersal, modulator, and IF filter modules plus an (optional) switch-selectable frequency agile upconverter.

Series 461 Dual-Conversion Upconverter section proposed is designed for use in wideband communications systems to convert an intermediate frequency of 70 MHz to any fixed carrier frequency within the 5925 to 6425 MHz frequency band. Carrier frequency selection is made by means of the second local oscillator only, with all filters remaining fixed-tuned. A 70 MHz IF amplifier precedes the first upconversion and provides automatic leveling of the RF output. A control is provided to set the operating RF output level.

The upconverter is packaged in a single 5 - 1/4 inches high x 19 inches wide chassis which is designed for standard rack mounting. Seven plug-in module slots are available in the upconverter chassis. These slots are used to accomodate energy dispersal, baseband processing, modulator, IF filter, equalizer, and alarm modules when the upconverter is used as part of a complete baseband RF-transmitter exciter.

The wideband modulator is designed for use with either video or message exciters in satellite communications earth stations. Modulator design consists of a series of plug-in modules which are installed in the blank mainframe space provided with the upconverter. Each modulation section consists of a baseband unit providing pre-emphasis, an energy dispersal unit, an FM transmitter, and an IF filter. Options such as transmit alarms and baseband combiners are also available.

A block diagram of the Series 461 Exciter is shown in Figure 2-1. A summary of technical specifications for the Series 461 Message Exciter follows:



Series 461 Message Exciter, Photo 6741

## Series 461 Message Exciter Characteristics

Frequency Range
  5925 to 6425 MHz
Level
  −10 dBm to −20 dBm, 0 dBm available
Level Stability
  ±0.25 dB/day
Impedance
  50 ohms
Return Loss
  20 dB minimum
Frequency
  Dual conversion with switch-selectable crystal oscillators and manually tuned second local oscillator
Local Oscillator Stability
  1 part in $10^6$/day
  2 part in $10^7$/°C (0 to 50°C)
IF to RF Amplitude Response
  0.25 dB, $f_o$ ±18 MHz
Modulator Linearity
  1%, $f_o$ ±18 MHz

Operating Parameters
  Message Deviation Range
    100 to 1000 kHz 0 dBm 0 test tone deviation
  IF Bandwidths
    2.5 MHz to 36 MHz

Message Input
  Frequency Response (BB-RF)
    4 to 12 kHz, ±0.5 dB
    12 kHz to $f_v$ maximum, ±0.25 dB
  Level
    −25 to −40 dBm, adjustable
  Impedance
    75 ohms, unbalanced
  Return Loss
    26 dB

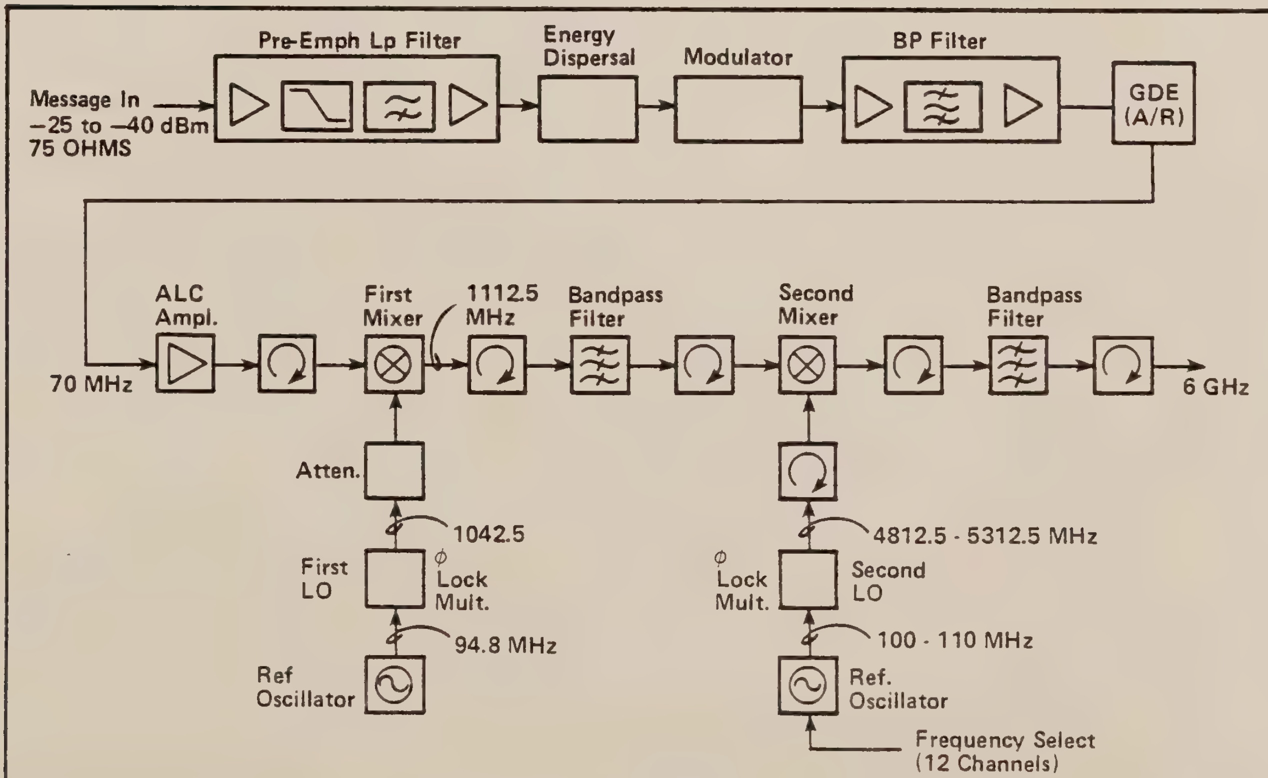



Figure 2-1. Block Diagram Series 461 Dual-Conversion Message Exciter.

## MESSAGE EXCITER MODULE DESCRIPTION

**Exciter Mainframes**

The mainframes are standard 19 inch rack mounted designs that are 5.25 inches high. The mainframe is a U-shaped aluminum chassis with an integral rear panel that contains all input/output connections. All operating controls are located on the front panel.

DC operating voltages are carried to the interface connectors of all modules, whether or not a module is inserted. Signal input and output interconnections are made via the rear panel (see Photo No. 8489) connectors so that, with the appropriate external patch cables connected, the modules in any configuration will be properly interconnected. Rear-panel patches are also furnished for such signals as the 70 MHz IF and 2nd local oscillator reference to permit access to these signals for system testing and/or calibration.

Signal flow through the exciter is quite straightforward and is illustrated by the functional block diagram of the mainframe (Figure 1A).

The left hand section of the unit contains the local oscillator for the modulator. The right section of the mainframe provides slide-in mounting facilities for the IF and baseband processing modules. Machined tracks in a plate at the bottom of the chassis guide the modules smoothly into position so they will positively mate with interface connectors on a bracket near the rear of the chassis. One important feature of Scientific-Atlanta's GCE is that the second slot from the right, with the mainframe viewed from the front, can be used as a test slot. The pins of the interface connector on the module plugged into the test slot are brought out to the rear of the chassis. In this way, the power supply can be used to power the module while it is under test. The unit may or may not be operational, however, under these conditions.

The Model 402A Power Supply is a plug-in unit intended to furnish dc power to modules of the Scientific-Atlanta Series 400 equipment. Four voltages are produced: +24V dc, +12V dc, −24V dc, and −12V dc. Current limiting is furnished for all four supplies; overvoltage protection in the form of a crowbar circuit is provided on the 12 volt supplies.

Ripple and noise on the output of the supplies is typically less than 10 mV peak-to-peak for the 24 volt supplies, and 5 mV peak-to-peak for the 12 volt supplies. Total load and line regulation for all supplies is typically less than 0.5%. This unit mounts on the rear apron of each chassis.

With regard to controls/metering of the mainframe, the units have a multifunction meter with associated function switch. The following tabulations provide the characteristics of the controls and metering.

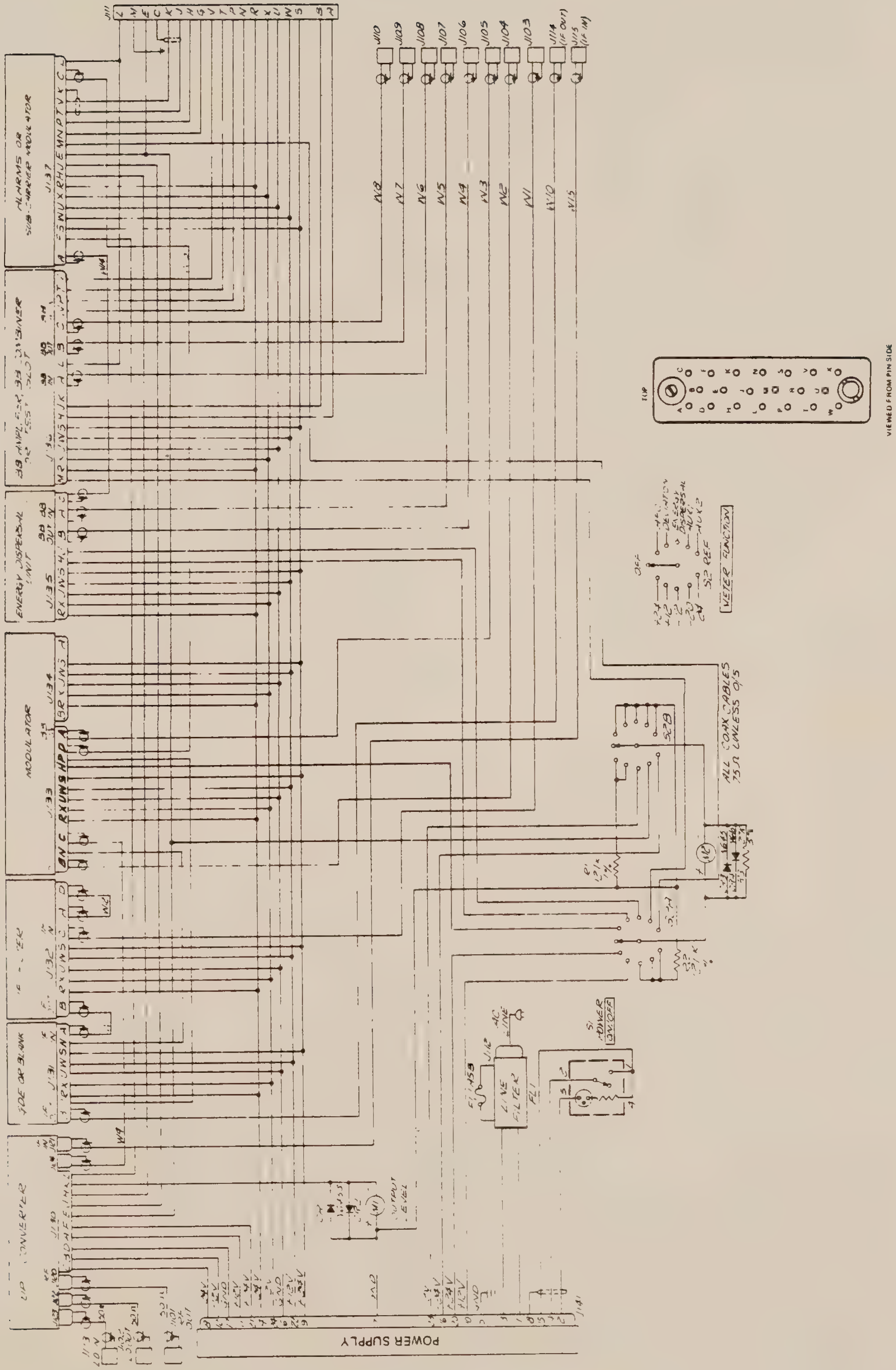
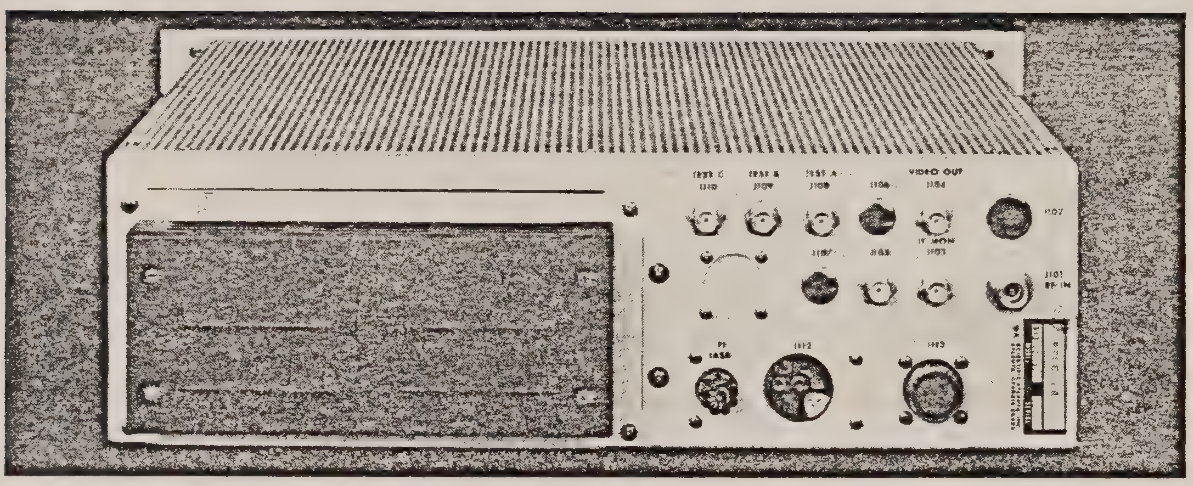



Figure 1A. Series 461WB Exciter Mainframe.



Model 461WB Rear Panel, Photo 6336

**Exciter Mainframe Controls and Indicators**

| Control/Indicator | Position | Function |
|---|---|---|
| Meter Function Switch | OFF | Meter disconnected |
| | -24 | Meter reads voltage on exciter -24V dc bus |
| | -20 | Meter reads output from -20V dc supply in upconverter (derived from exciter -24V dc bus) |
| NOTE<br>Read voltages on top meter scale | -12 | Meter reads voltage on exciter -12V dc bus |
| | +12 | Meter reads voltage on exciter +12V dc bus |
| | +24 | Meter reads voltage on exciter +24V dc bus |
| | AFC<br>Deviation<br>Dispersal<br>AUX 1<br>AUX 2 | These switch positions connect the meter to read various baseband and other levels at the inputs and outputs of the modules plugged into the mainframe |

**Frequency Upconverters** The frequency upconverter utilized in the exciters is Scientific-Atlanta's Standard Model 461WB(D) 5.9 - 6.4. This unit bolts into the extreme left hand side of the mainframe. Power and interconnections to the rear apron terminals are made in the mainframe.

The frequency upconverters utilized in Scientific-Atlanta's Series 461 Exciters are dual conversion units that have an output frequency in the 5.925 - 6.425 MHz band. The input frequency is an IF signal in the 52 - 88 MHz range. The standard model has 12 switch-selectable output frequencies and as options the particular frequency can be remotely selectable or can be synthesizer controlled. The upconverter plugs into the left hand position at the mainframe and all interconnections, signal and power are made inside the mainframe.

The function of the upconverter is to convert the incoming 70 MHz IF signal to the desired transmit RF channel frequency. This is accomplished in two frequency conversions. The first conversion is to an IF of 1112.5 MHz. At this IF, signals are filtered and then further converted to 5.925 - 6.425 GHz. Figure 2A is the upconverter block diagram.

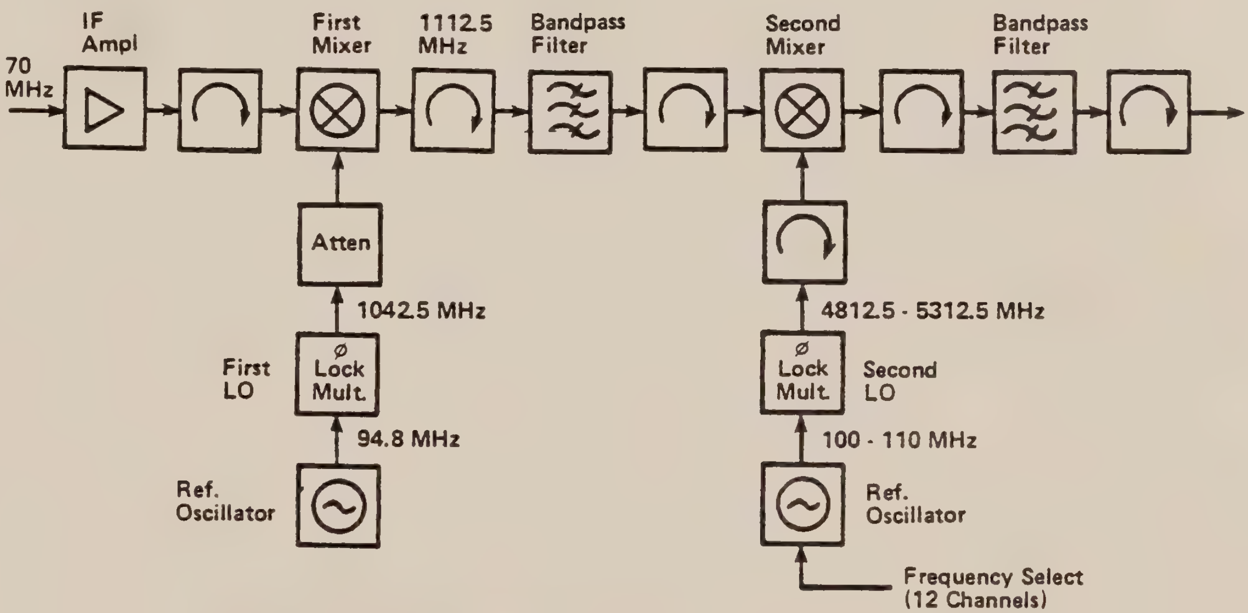
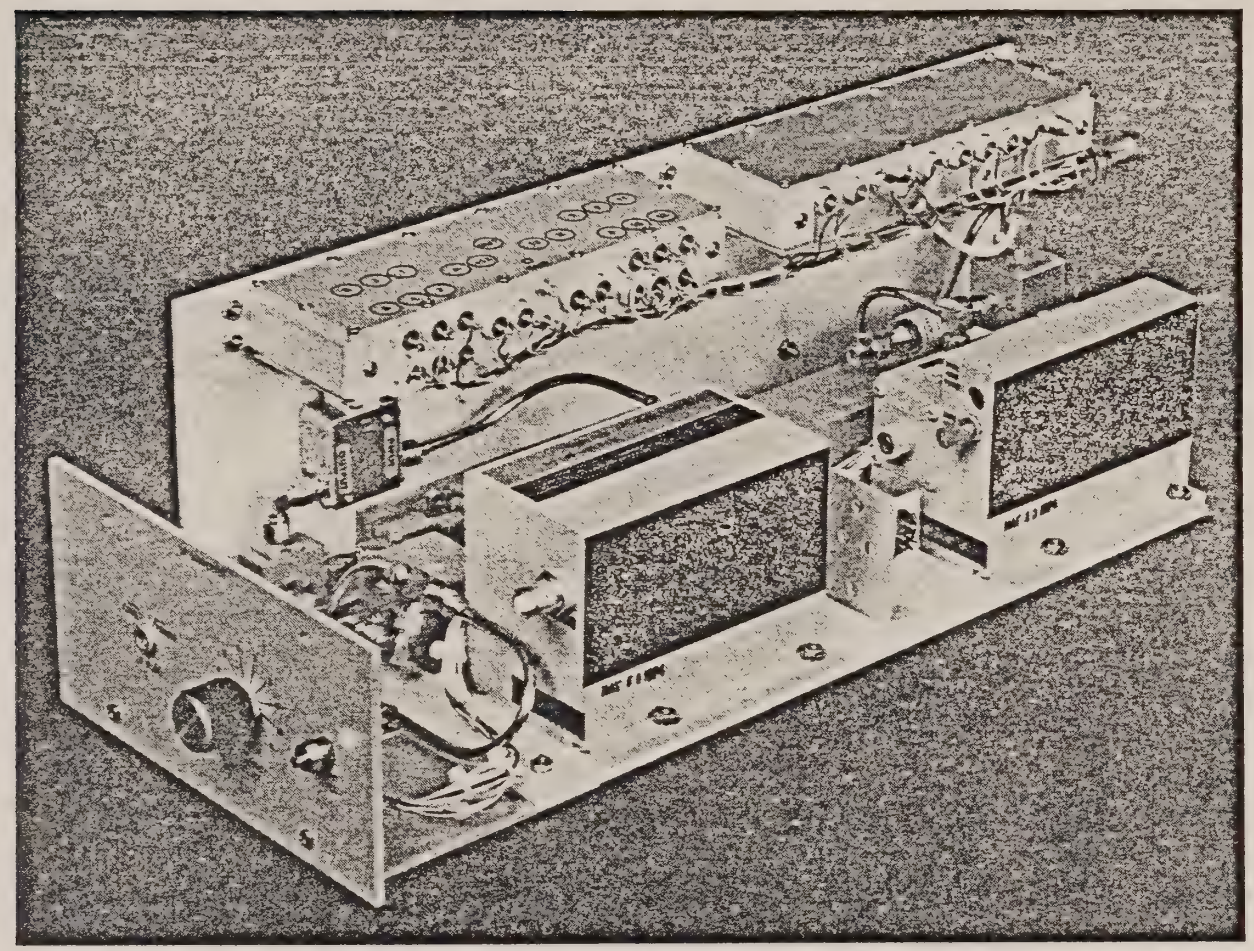



Figure 2A. Block Diagram Series 461 Dual Conversion Upconverter

Signals entering the upconverter first pass through an input amplifier, a three stage amplifier that amplifies the IF signal to a maximum level of +7 dBm (nominal). It contains an internal AGC loop that is controlled by the external level-setting potentiometer. The AGC loop provides automatic leveling (ALC) of the upconverter IF output. The level-setting potentiometer allows varying the output of the IF amplifier and hence the upconverter output over a range in excess of 10 dB.



**Model 461WB(D) 5.9-6.4 Upconverter Module, Photo 6634**

The output of the IF amplifier is fed to a mixer, which upconverts the 70 MHz IF signal to the first IF of 1112.5 MHz. The mixer local oscillator for this conversion is accomplished by a phase-locked multiplier source operating at a fixed frequency of 1042.5 MHz. The output of the phase-locked source is attenuated by approximately 12 dB of attenuation to result in a LO drive level between +12 and +15 dBm at the LO port of the mixer. The IF output at 1112.5 MHz is then fed to a filter. The filter is equipped with input and output isolators to provide low VSWR terminations for the filter. The function of this filter is to provide attenuation of the first conversion image, other mixer spurious products, and the 1042.5 MHz local oscillator signal. After filtering, the signal is fed to the IF port of a second mixer which upconverts the 1112.5 MHz IF signal to an output frequency in the 5925 to 6425 MHz range. Upconverters equipped with the power output option have an amplifier inserted between the filter and the IF port of the mixer to provide approximately 10 dB of IF amplification prior to the final conversion. The output frequency of the final conversion is determined by the frequency of its local oscillator which is supplied by phase-locked multiplier. This

oscillator operates in the 4812.5 to 5312.5 MHz range and provides a net reference frequency multiplication of X48. The reference frequency for this multiplication may be obtained from an internal crystal oscillator, from an external signal generator or synthesizer, or optionally from an internal synthesizer. The reference frequency lies in the 100 to 110 MHz range. The reference oscillator frequency for a given output frequency is determined by the following relationship:

$$f_{ref} = \frac{f_{tx} - 1112.5}{48}$$

After conversion to the final output frequency, the RF signal is passed through a bandpass filter. This filter provides attenuation of the final conversion image frequency and attenuation of the local oscillator frequency fed through mixer. It also provides attenuation of out-of-band spurious mixing products.

The upconverter includes an integral −20 volt regulator to operate the phase-lock sources. This regulation is accomplished by transistor regulator Q1 referenced to the Zener diode CR2 and diode CR1.

The upconverter controls are located on the front panel and are:

Frequency Select

Selects the frequency to be transmitted. In the standard upconverter, the switch positions are marked 1 through 12.

LO Mode

During normal operation, this switch is left in the Local position, and the frequency of the 1st LO is determined by the front panel Frequency Select switch. In the Remote position, 1st LO frequency is determined by an external source, external switch, or internal synthesizer.

## UPCONVERTER TECHNICAL CHARACTERISTICS

**Input**
- Frequency
  - 70 MHz ±20 MHz
- Level (without IF filter)
- Nominal
  - −10 dBm
- Maximum
  - −5
- Minimum
  - −20
- Level (with IF filter)
- Nominal
  - −18 dBm
- Maximum
  - −13 dBm
- Minimum
  - −28 dBm
- Impedance
  - 75 ohms unbalanced
- Return Loss
  - 26 dB over IF bandwidth
- Bandwidth
  - 40 MHz

**Output**
- Frequency
  - 5925 to 6425 MHz
- Level
- Standard
- −10 dBm to −20 dBm
- Optional
- 0 dBm to −10 dBm
- Level Stability
  - ±0.25 dB/day, 25°C
- Impedance
  - 50 ohms
- Return Loss
  - 20 dBm minimum

**IF to RF**
- Gain Response
  - ±0.25 dB, $f_o$ ±18 MHz
- Delay Distortion
- Linear
  - 0.03 ns/MHz, $f_o$ ±18 MHz
- Parabolic
  - 0.01 ns/MHz$^2$, $f_o$ ±18 MHz

**Spurious Outputs**
- <−100 dBm/4 kHz

**Local Oscillator**
- Standard
- Frequencies
  - 12 switchable
- Stability
  - 1 part in $10^6$/day (25°C)
  - 2 parts in $10^7$/°C (0 - 50°C)
- Optional
- Frequencies
  - 1 to 12 as specified
- Stability
  - ±200 Hz/day (15 - 35°C)
- Synthesizer
  - 5925 - 6425 MHz in 0.25 MHz steps

**Weight**
- 40 lbs

**Power Consumption**
- 105 - 125V ac, 47 - 63 Hz or
- 210 - 250V ac, 47 - 63 Hz, 150W

**IF Filters** The IF Filters (see Photo No. 6623) are front panel plug-in modules for operation with the Series 411 Receivers and Series 461 Exciters. These units plug into specific slot assignments of the mainframe and receivers operating power from the mainframe power supply. Connections are made to the filter through an interface connector on the rear of the module.

The purpose of the filter is to provide rejection of unwanted out-of-band signals and to provide amplification of the desired in-band signals. In addition, equalization of group delay due to the filter is provided. The following is a block diagram of the IF filter.


Figure 3A. IF Filter Block Diagram

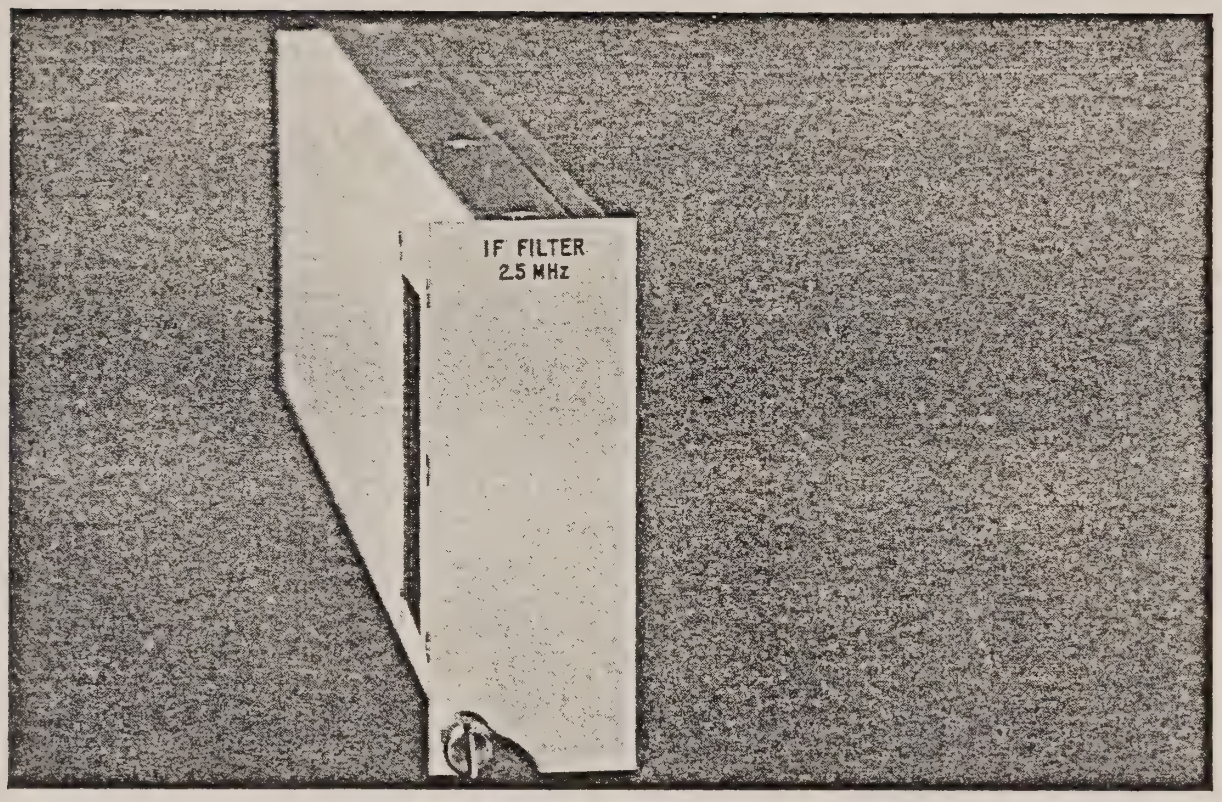
The technical characteristics of the IF filters are listed in the following table:

| BW (MHz) | Max Input Level | Receiver Gain | Exciter Gain |
|---|---|---|---|
| **Narrow Band Filters** | | | |
| 2.5 | −24.6 dBm | 19.8 ±1 dB | 8 ±2 dB |
| 5.0 | −21.6 dBm | 16.6 ±1 dB | 8 ±2 dB |
| 7.5 | −19.8 dBm | 14.8 ±1 dB | 8 ±2 dB |
| 10 | −18.6 dBm | 13.6 ±1 dB | 8 ±2 dB |
| **Wideband Filters** | | | |
| 15.0 | −16.8 dBm | 11.8 ±1 dB | 8 ±2 dB |
| 17.5 | −16.1 dBm | 11.1 ±1 dB | 8 ±2 dB |
| 20.0 | −15.6 dBm | 10.6 ±1 dB | 8 ±2 dB |
| 25.0 | −14.6 dBm | 9.6 ±1 dB | 8 ±2 dB |
| 30.0 | −13.8 dBm | 8.8 ±1 dB | 8 ±2 dB |
| 36.0 | −13.0 dBm | 8.0 ±1 dB | 8 ±2 dB |

*1.25 MHz Bandwidth Filters are being added.

Table 4A. IF Filter Characteristics

IF filter amplitude and delay characters are shown in Figures 5B and 6B.




IF Filter Module, Photo 6623

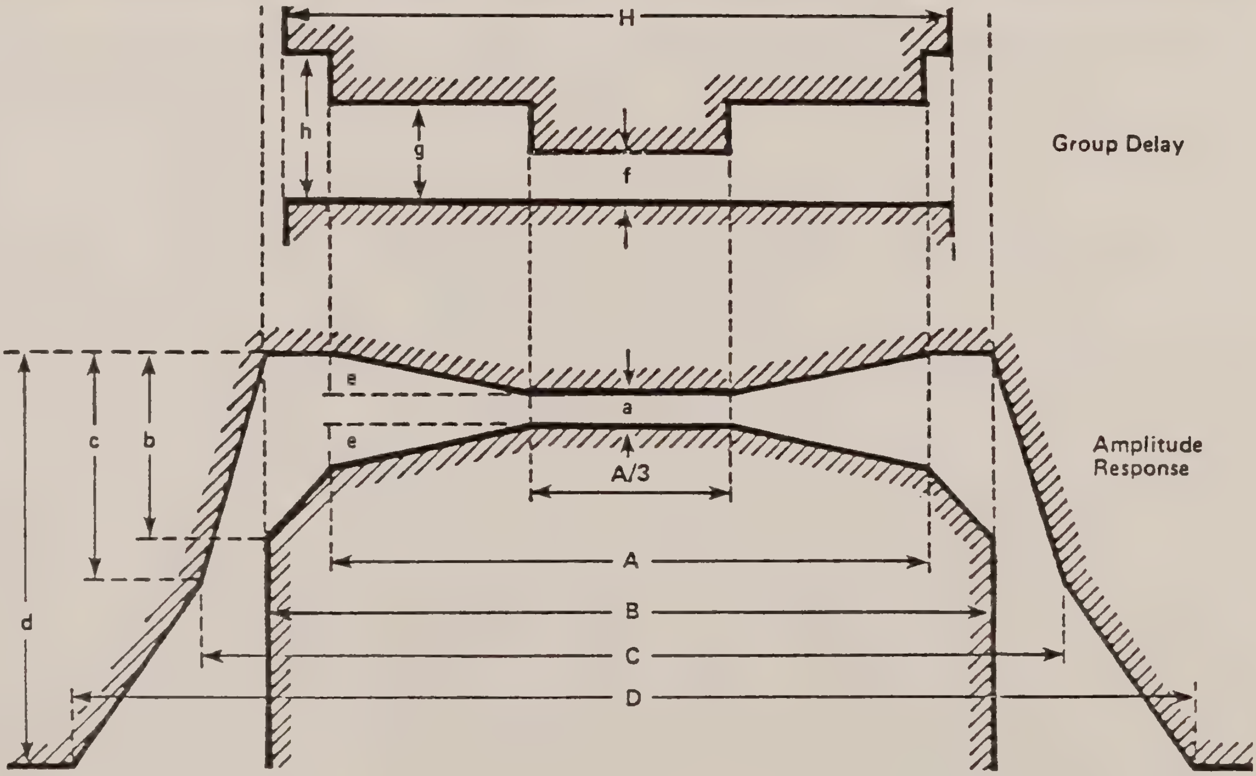



Figure 5A. IF Filter Amplitude-Delay Characteristics.

| S-A Part No | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131621 | 2.5 | 1.8 | 2.25 | 2.75 | 8.0 | 0.7 | 1.5 | 2.5 | 25 | 0 | 2.1 | 16 | 16 | 20 |
| 131622 | 5 | 3.6 | 4.5 | 5.25 | 13.0 | 0.5 | 2.0 | 3.0 | 25 | 0 | 4.1 | 12 | 12 | 20 |
| 131623 | 7.5 | 5.4 | 6.75 | 7.75 | 17.0 | 0.4 | 2.5 | 4.0 | 25 | 0 | 6.2 | 12 | 12 | 20 |
| 131624 | 10 | 7.2 | 9.0 | 10.25 | 19.0 | 0.3 | 2.5 | 5.0 | 25 | 0.1 | 8.3 | 9 | 9 | 18 |

| S-A Part No. | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131625 | 15 | 10.8 | 13.5 | 15.5 | 25.0 | 0.3 | 2.5 | 5.5 | 25 | 0.1 | 12.4 | 6 | 6 | 15 |
| 131626 | 17.5 | 12.6 | 15.75 | 18 | 26.5 | 0.3 | 2.5 | 6.5 | 25 | 0.1 | 14.2 | 6 | 6 | 15 |
| 131627 | 20 | 14.4 | 18.0 | 20.5 | 28.0 | 0.3 | 2.5 | 7.5 | 25 | 0.1 | 16.6 | 4 | 5 | 15 |
| 131628 | 25 | 18.0 | 22.5 | 25.75 | 34.0 | 0.3 | 2.5 | 8.0 | 25 | 0.2 | 20.7 | 3 | 5 | 15 |
| 131930 | 36.0 | 28.8 | 36.0 | 45.25 | 60.0 | 0.6 | 2.5 | 10.0 | 25 | 0.3 | 33.1 | 3 | 5 | 15 |
| 131929 | 30 (video) | 24.0 | 30.0 | – | – | 0.5 | 2.5 | – | – | 0.3 | 30.0 | 5 | 5 | 15 |

**Figure 6A. IF Filter Amplitude-Delay Characteristics.**

**Modulator — Part No. 131725**

The modulator accepts processed baseband signals as an input and produces a modulated IF carrier centered at 70 MHz. The output level is compatible with the upconverter input level requirements. The modulators are capable of operating at any channel capacity between 24 and 1872 channels and with any video format.

The modulator accepts baseband signals as an input and produces a modulated IF output. It contains AFC circuitry to accurately control carrier center frequency and provides suitable status alarms and monitors. Referring to the block diagram, the baseband input signal is first buffered in a baseband amplifier. The amplifier contains gain adjustment facilities to set the deviation constant of the modulator. The baseband signal is ac coupled into a VCO operating at 1112.5 MHz. The ac coupling provides flat frequency response down to 20 Hz. The VCO is the deviation mechanism in the modulator. Operation at 1112.5 MHz provides extremely linear deviation as a function of baseband input level and is also a convenient frequency to use in that it can be mixed to 70 MHz by using an LO output from the upconverter first local oscillator. Following mixing to 70 MHz, the carrier is buffered and a sample is split out to operate the AFC circuitry. An additional output buffer amplifier is provided following the splitter to provide the final IF output. The AFC circuitry consists of a discriminator which alternately samples the modulator 70 MHz output and the output of a 70 MHz crystal oscillator. The alternate samples are stored in sample and hold circuits at the discriminator output and compared in a differential amplifier. The differential amplifier produces an AFC loop error signal which is direct coupled to the VCO input through appropriate filtering. The loop operates to drive the FCO center frequency to 1112.5 MHz which produces 70 MHz at the modulator IF output. An AFC alarm detector is provided to detect excessive AFC errors. A sample of the baseband input just prior to application to the FCO optional baseband pilot continuity alarm. A block diagram of the Scientific-Atlanta modulator is shown in Figure 7A.

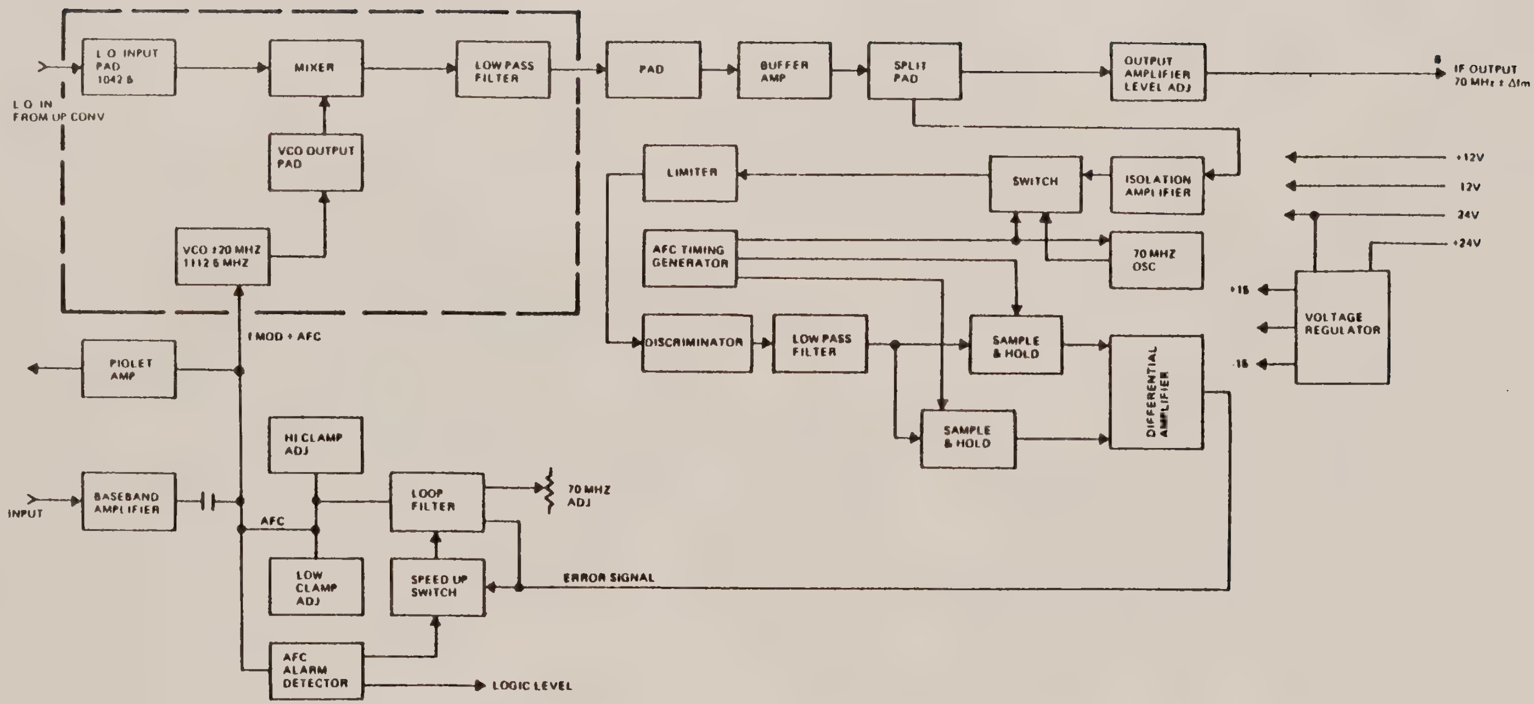
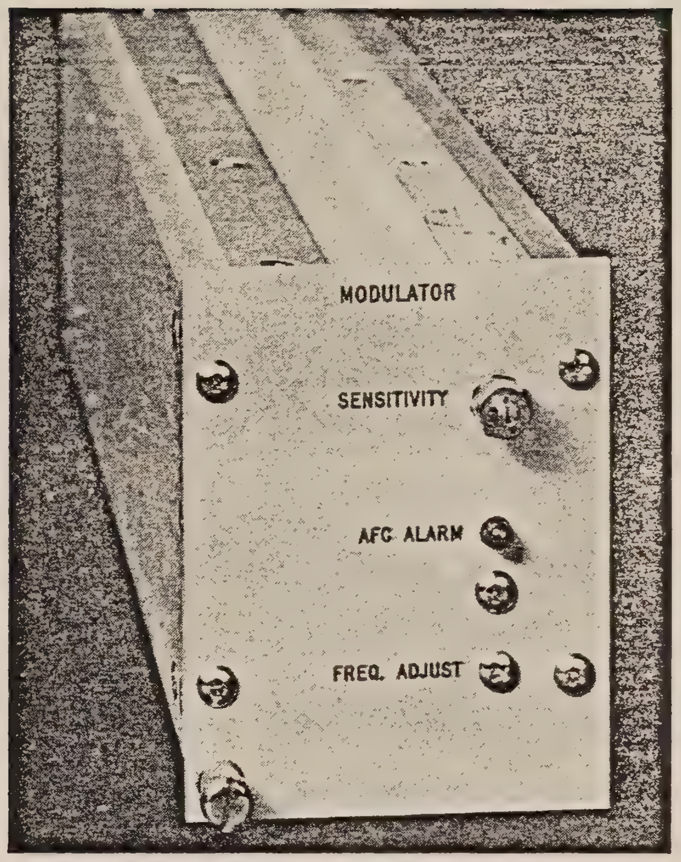



Figure 7A. Message Modulator Block Diagram




Frequency Modulator Transmitter, Photo 6955

Baseband Input Impedance
75 ohms, unbalanced
Baseband Return Loss
26 dB min (20 Hz to 8.3 MHz)
IF Output Impedance
75 ohms, unbalanced
IF Output Return Loss
26 dB min (52 - 88 MHz)
Channel Capacity
12 to 1872 channels and all deviations per BG28-72E
Video
All 525L and 625L formats
Frequency Response
±0.2 dB (20 Hz to 8.3 MHz)
IF Amplitude Response
±0.25 dB (52 MHz - 88 MHz)
Baseband Level Stability
±0.1 dB per day
±0.3 dB pér month
IF Output Level
−18 dBm, nominal

IF Output Frequency Accuracy
±50 kHz (long term and temporary)
Linearity
Better than 1% over ±18 MHz
Group Delay, Total
Less than 0.1 nsec ±18 MHz
Linear
±0.2 nsec/MHz
Parabolic
0.05 nsec/MHz$^2$
Ripple
0.6 nsec peak-to-peak
Group Delay Variation
Linear
±0.02 nsec/MHz per month
Parabolic
0.005 nsec/MHz$^2$ per month
Intermodulation Distortion
53 dB min
Spurious Output
−100 dBm per 4 kHz
Alarm Indication
Loss of AFC lock

**Energy Dispersal Module — Part No. 131773**

Energy dispersal unit (see Photo No. 6614) plugs into the front panel of the exciter mainframe and its purpose is to provide a controlled triangular waveform dispersal signal which is combined with the baseband signal before being fed to the modulator. Proportional control of the amount of energy dispersal injection is provided based on the baseband loading. Result is a nearly constant composite baseband plus dispersal level being fed into the modulator. A baseband power limiter is also provided in the EDU to reduce baseband power to the nominal full load value for inputs up to at least +10 dB above a fully loaded baseband.

Referring to the functional block diagram (Figure 2-22), the baseband signal is first amplified and then applied to a voltage-controlled capacitive voltage divider and source-follower amplifier. Output from the source-follower amplifier drives an output amplifier, which in turn drives the baseband signal through an output attenuator. Before the attenuator, however, the baseband signal is applied to an average-value detector whose output is low pass filtered and used to drive an AGC loop. Output from the loop filter is used to drive attenuator-driver amplifiers. These amplifiers are arranged so that all the dispersal signal is AGC'd off before any baseband signal is AGC'd. Output from a dispersal oscillator is passed through an attenuator and applied to the output amplifier. At a very low channel-loading level, the level of the trangular dispersal waveform is attenuated very little, and output to the system modulator is mainly dispersal waveform. However, as the channel loading of the carrier increases, the baseband level increases and the energy-dispersal waveform level decreases to the point at which there is very little dispersal waveform present. At full load, the dispersal waveform is at least 30 dB below baseband. Energy dispersal unit is designed to AGC at a constant power output of –8.75 dBm into 75 ohms with an output fine adjustment of ±0.4 dB. This level is then attenuated to the desired output level required for channel capacity rms deviations. To change channel capacity, only the value of the 3 plug-in pads need to be changed. No other circuit adjustment is required.

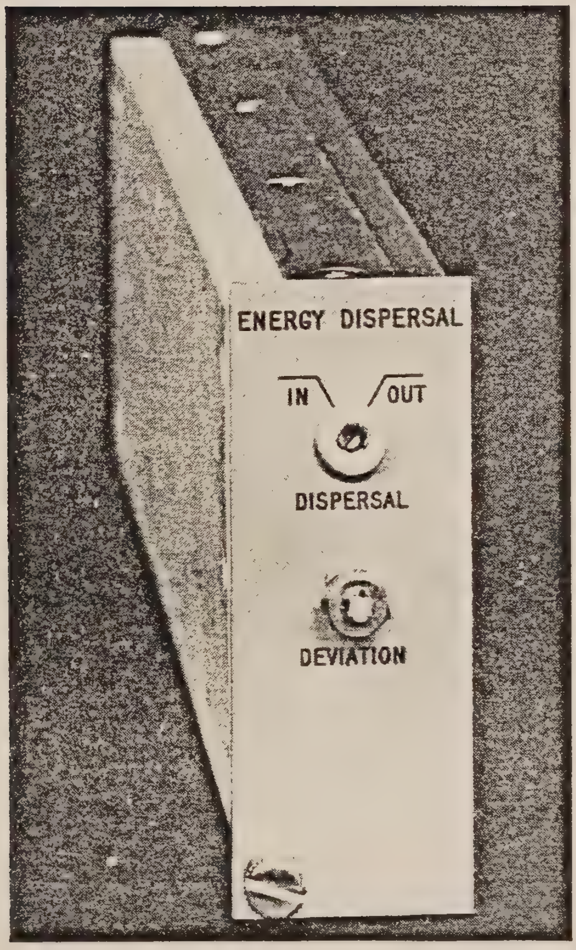
Several other outputs are provided, such as a deviation output signal from the AGC loop filter, a dispersal level signal, and a baseband-level alarm signal. The deviation alarm is set by a variable attenuator and produces a major system alarm. It may be set to alarm at any point up to +10 dB above nominal fully loaded input level. Alarm function is inactive when dispersal is switched out.

Output from the average-value detector and low pass filter may be read on the front-panel meter in the DEVIATION position of the METER FUNCTION switch. With dispersal switched in, meter will read the same for any baseband level from zero to +10 dB above the nominal. No actual calibration is provided for this indication, but it will be constant for each individual unit. The nominal reading will be from 1.0 to 1.5 on the V-BB scale.

In addition to the detector output, a dispersal level signal is provided that reads full scale for zero baseband level and nominally zero for full baseband loading.

All necessary operating controls are located on the front panel of the module. These are:

| Control | Function |
|---|---|
| Dispersal In/Out | Used to insert or remove the dispersal waveform. When the unit is switched out, the deviation alarm is disabled. |
| Deviation | Provides fine adjustment of the signal level out of the energy dispersal unit. |




Exciter Energy Dispersal Module, Photo 6614

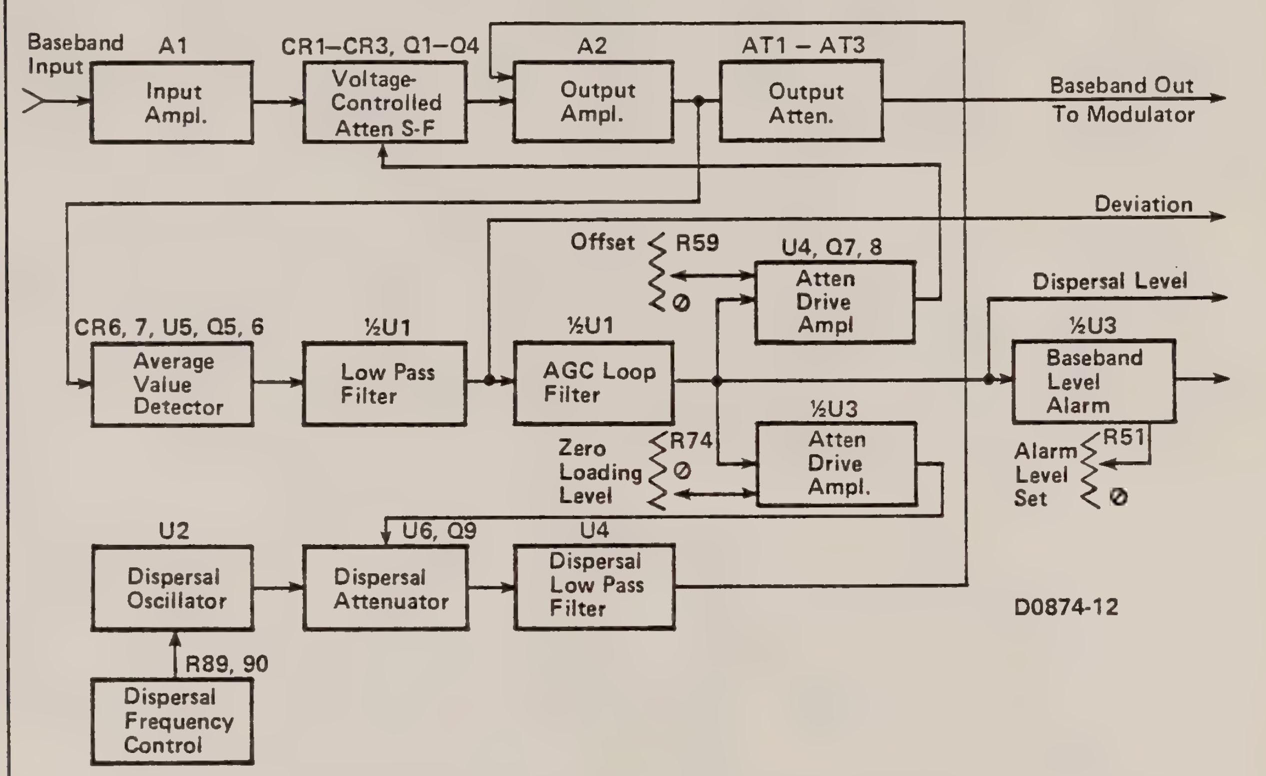



Figure 2-22. Energy Dispersal Unit Block Diagram.

## SUMMARY ENERGY DISPERSAL TECHNICAL CHARACTERISTICS

Input-Output Return Loss 3 kHz - 8 MHz
 26 dB
Dispersal Oscillator
 Adjustable 25 - 150 Hz internal adjustment
Dispersal Attenuation
 Proportional to baseband input level
Baseband Input Level
 −16.7 dBm 75 ohms for any loading
Output Level
 Set by plug-in pads (internal) for required drive level to FMT
Output Level Adjustment
 +0.4 dB front panel
Maximum Input Level with AGC Control
 −6.7 dBm, 75 ohms
Output Level Stability
 ±0.2 dB per month

**Exciter Baseband Amplifier — Part No. 131612**
The baseband amplifier is a module that plugs into the front panel of the mainframe. Within the module there are four separate plug-in modules; two amplifier modules, one noise slot bandstop and roofing filter, and one pre-emphasis module.

All of these plug into a mother board which provides interconnection between modules as well as providing pads from which front and rear connections are made. Changing channel capacities is easily accomplished by changing the plug-in pre-emphasis board and the noise slot bandstop and roofing filter. A complete listing of these follows:


Transmit Baseband Amplifier, Photo 6619

Pre-Emphasis Boards (Per CCIR Rec. 275-2 and BG28-72E)

| Channel Capacity | fm (kHz) | Part Number |
|---|---|---|
| 12 | 60 | TBD |
| 24 | 108 | 131752 |
| 36 | 156 | 131753 |
| 60 | 252 | 131754 |
| 72 | 300 | 131755 |
| 96 | 408 | 131756 |
| 132 | 552 | 131757 |
| 192 | 804 | 131758 |
| 252 | 1052 | 131759 |
| 312 | 1300 | 131760 |
| 432 | 1796 | 131761 |
| 612 | 2540 | 131762 |
| 792 | 3284 | 131763 |
| 972 | 4028 | 131764 |
| 1092 | 4892 | 131765 |
| 1872 | 8120 | 131766 |

Noise Slot Bandstop Filter (Per BG28-72E)

| Capacity | $f_c$ (kHz) | Part Number |
|---|---|---|
| 12 | 66 | TBD |
| 24 | 116 | 131774 |
| 36 | 172 | 131775 |
| 60 | 277 | 131776 |
| 72 | 331 | 131777 |
| 96 | 448 | 131778 |
| 132 | 607 | 131779 |
| 192 | 884 | 131780 |
| 252 | 1157 | 131781 |
| 312 | 1499 | 131782 |
| 432 | 1976 | 131783 |
| 612 | 2794 | 131784 |
| 792 | 3612 | 131785 |
| 972 | 4430 | 131786 |
| 1072 | 5381 | 131787 |
| 1872 | 8932 | 131788 |

Power is furnished from the mainframe power supply. A block diagram of the unit is shown in Figure 2-21. BB signal first passes through a variable attenuator which controls the signal level out of the module. A blocking capacitor prevents any offsets due to possible dc voltage on the incoming signal. After being amplified, the signal then passes through either the pre-emphasis network (with the front-panel switch in the PRE-EMP position) or a 5 dB attenuator (with the front-panel switch in the FLAT position). Normal operating position is the PRE-EMP position with the FLAT position typically used only for testing purposes. Signal then passes through the lowpass filter and noise slot bandpass filter. The signal is then capacitively coupled to an output amplifier module which is the final gain block.

Plug-in amplifiers are dc coupled amplifiers that have a flat frequency response to approximately 10 MHz. Amplifiers operate in the non-inverting configuration. A variable potentiometer is provided to set the dc output level with no input signal.

Pre-emphasis boards consist of a pre-emphasis network which meets the requirements of CCIR Recommendations 275-2 and BG28-72E. Input and output impedance is 75 ohms. In addition there is a 5 dB, 75 ohms, attenuator (which is the approximate loss of the pre-emphasis network at the pre-emphasis crossover frequency) that is switched in when the entire receive baseband amplifier is tested for flatness. The following controls are located on the front panel of the module:

**Pre-Emp/Flat Switch** — Screwdriver operated switch which switches in the pre-emphasis network (PRE-EMP) or a 5 dB attenuator (FLAT). The normal operating position is PRE-EMP.

**BB Level (BB2)** — Locking potentiometer which adjusts the output level. This is a set-up control and should not require readjustment once a system at a channel capacity has been set up.

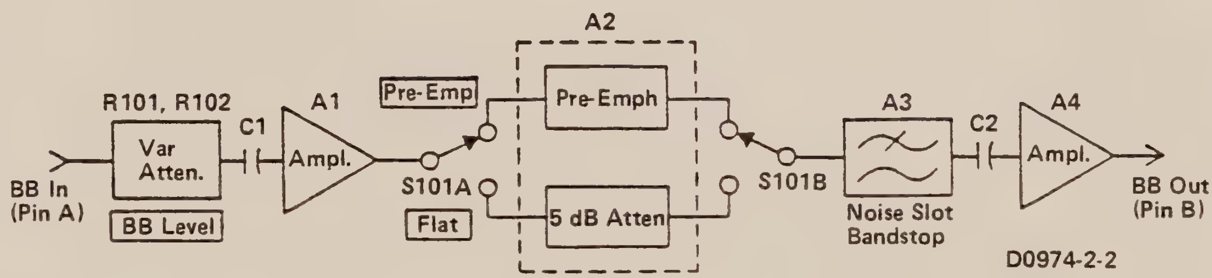
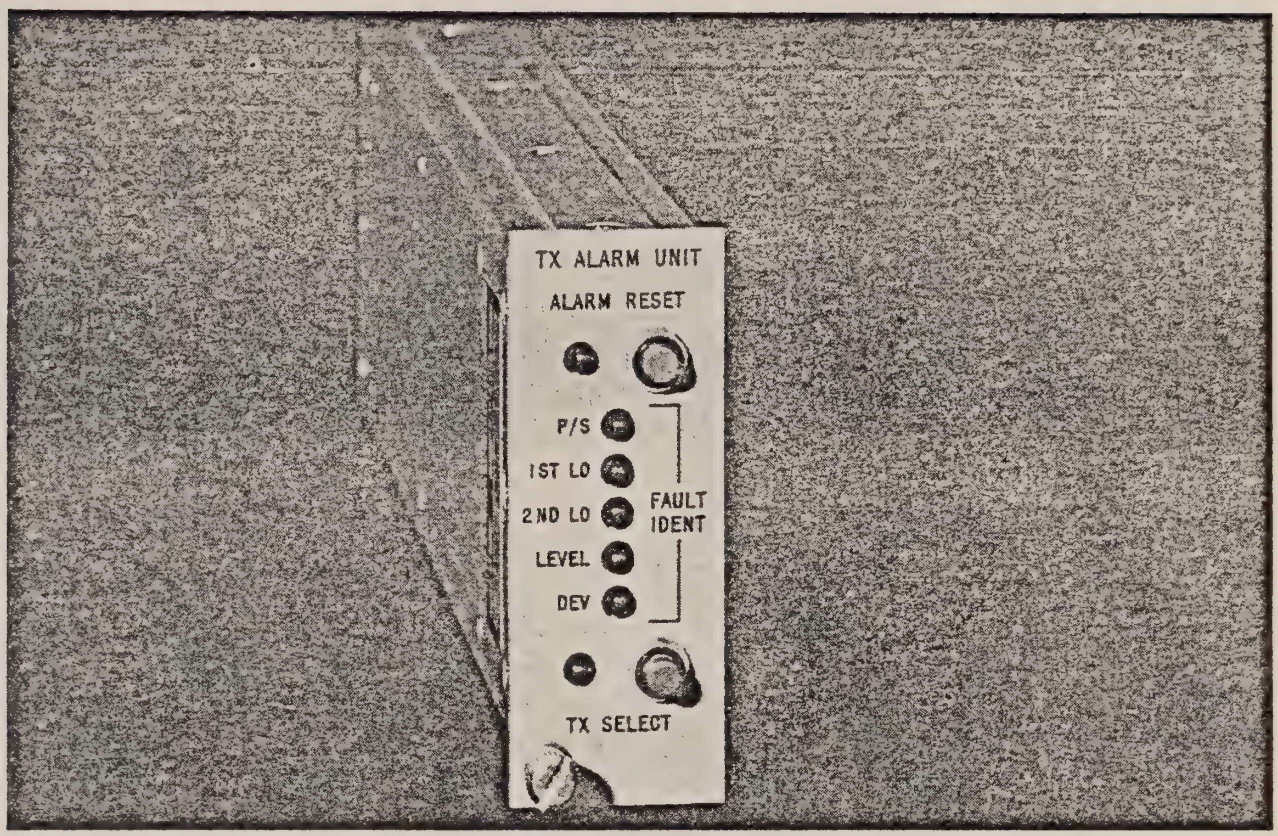



Figure 2-21. Message Exciter Baseband Amplifier Block Diagram.

TRANSMIT BASEBAND AMPLIFIER TECHNICAL CHARACTERISTICS

Input/Output Impedance
75 ohms
Gain (at the Pre-Emphasis Crossover Frequency)
+25 dB minimum

Frequency Response
4 - 12 kHz
$\leqslant \pm 0.4$ dB
12 kHz - maximum frequency
$\leqslant \pm 0.2$ dB




Exciter Alarm Module with Fault Indicators, Photo 6618

**Tx Alarm** The transmit alarm unit (Photo No. 6618) is a plug-in unit for utilization in the Series 461 Exciters. The alarm unit senses the following signals within the complete exciter chain.

a. TX Level
b. Power Supplies (5 voltages)
c. First LO Phase Lock
d. Second LO Phase Lock
e. Deviation Alarm

For IF monitoring, alarm "d" is disabled. When one, or all, of these signals fault or an out-of-tolerance condition exists, the exciter alarm unit is triggered. Once triggered, a LED indicator on the front panel of the module illuminates to designate the particular fault and a summary relay contact closure is provided to the rear connector. This contact closure is available for utilization in the overall fault logic.

A Reset pushbutton is used to reset the alarm circuits after a fault has been cleared and a Tx Select pushbutton is used to select the desired exciter. The seven LED indicators illuminate to show where the fault occurred and which exciter has been selected.

The five Fault Ident indicators will remain illuminated if the fault clears itself. The Alarm indicator, however, will stay illuminated only as long as the fault condition exists.

The Tx Select indicator is illuminated when the Tx Select pushbutton is depressed, and remains illuminated until either a fault occurs or the other exciter is selected.

Function
  Exciter alarm indication and signaling
Exciter Functions Monitored
  +24V dc
  −24V dc
  −20V dc (upconverter)
  +12V dc
  −12V dc
  First LO phase lock (upconverter)
  Second LO phase lock (upconverter)
  TX Level
  Deviation
Voltage Alarm
  ±30% from nominal value
Phase Lock Alarms
  First LO Alarm
    Upon loss of −20V dc from first LO in upconverter
  Second LO Alarm
    Upon receipt of phase lock loop search from second LO in upconverter (typically 18 volt peak-to-peak sawtooth waveform)
TX Level Alarm
  Voltages >+0.2 volt or >−0.2 volt
Dev. Alarm
  Current >0.1 mA into Q16 base
Outputs
  Alarm
    Relay contact closure and TTL logic signal >+2.4 volts
  TX Select
    Switch closure to signal return
Inputs
  Receiver Voltage
    +24V dc and −24V dc at 10 mA (sense only)
    +12V dc and −12V dc at 200 mA
    −20V dc at 10 mA (sense only)
  First LO
    −20V dc at 2 mA from upconverter
  Second LO
    Phase lock search signal, 60 Hz, 18V peak-to-peak sawtooth
  TX Level
    Normal voltage −0.2 to +0.2 volts: Alarm condition outside these limits
  Dev. Alarm
    Input current >0.1 mA into Q16 base
  TX Select
    Voltage >2.4 volts turns on TX Select indicator

## APPENDIX B

### Scientific-Atlanta Series 411 Message Receiver

Scientific-Atlanta's Series 411 Message Receivers are integrated receiving systems. As with the Series 461 Exciters, fully-interchangeable plug-in modular construction results in simplified maintenance and repair. Also built-in monitoring and test facilities permit rapid status evaluations. The demodulators, IF amplifier, and IF filter sections are designed as plug-in modules to the basic dual-conversion downconverter chassis. Photograph 8800 shows a typical Series 411 Message Receiver equipped with (optional) switch-selectable frequency-agile downconverter plus demodulator, IF units, and baseband processing unit.

The dual-conversion downconverter is designed for use in wideband communication systems to convert any message carrier signal within the 3700 to 4200 MHz frequency band to an intermediate frequency of 70 MHz. Carrier frequency selection is made by means of the first local oscillator only, with all filters remaining fixed-tuned. Optional frequency-agility feature makes it possible for each receiver to tune rapidly to any carrier in the band. RF input filter does not introduce significant group delay variations over the band thus eliminating equalization adjustments as frequency is changed.

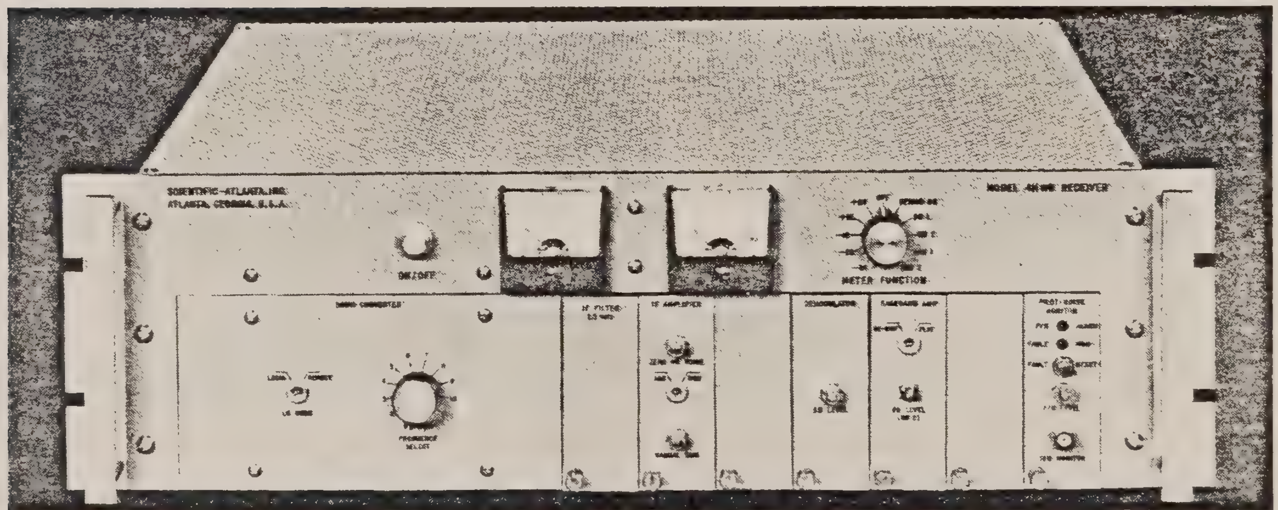
IF amplification with adjustable manual gain control or AGC is provided on all receiver configurations.

The downconverter is packaged in a single 5 - 1/4 inches high x 19 inches wide chassis which is designed for standard rack mounting.

After downconversion to an intermediate frequency (IF) of 70 MHz, the carriers are amplified, equalized, and demodulated by means of an FM discriminator capable of handling transmission bandwidths of ±18 MHz. Receiver baseband processing units provide facilities to de-emphasize and remove the energy dispersal waveform from the demodulated baseband signal.

Baseband signals are first processed through a de-emphasis network selected for the proper line parameters. This signal is then passed through a 4 kHz high-pass filter circuit to remove the dispersal waveform. After filtering, the message signal is processed through a final amplifier that allows adjustment of the output level.

A block diagram of the Series 411 Receiver is shown in Figure 2-2. A summary of technical specifications for the Series 411 Message Receiver follows:




Series 411 Message Receiver, Photo 8800

## SERIES 411 MESSAGE RECEIVER CHARACTERISTICS

Frequency Range
  3700 to 4200 MHz
Impedance
  50 ohms
Return Loss
  20 dB
Frequency Selection
  Dual conversion with switch-selectable crystal oscillators with manually tuned first local oscillator
LO Stability
  1 part in $10^6$/day
  2 parts in $10^7$/ °C (0 to 50°C)
Amplitude Response, RF-IF
  ±0.25 dB, $f_o$ = ±18 MHz
Gain Control
  AGC mode/manual mode 40 dB range, nominal
Demodulator Linearity
  1%, $f_o$ ±18 MHz
Spurious Response
  Greater than 65 dB below desired signal
Local Oscillator Leakage
  −80 dBm, maximum

**Operating Parameters**
  Maximum Output
    As defined for specific channel capacities
  Deviation Range
    As required for specific channel capacity at the de-emphasis crossover frequency
  De-Emphasis
    Per CCIR 275-2
  IF Bandwidths
    2.5 to 36.0 MHz
**Baseband Output**
  Frequency Response (RF-BB)
    4 kHz to 12 kHz, ±0.5 dB
    12 kHz to $f_v$ maximum, ±0.25 dB
  Impedance
    75 ohms
  Return Loss
    26 dB
  Level
    −25 dBm to −40 dBm, nominal

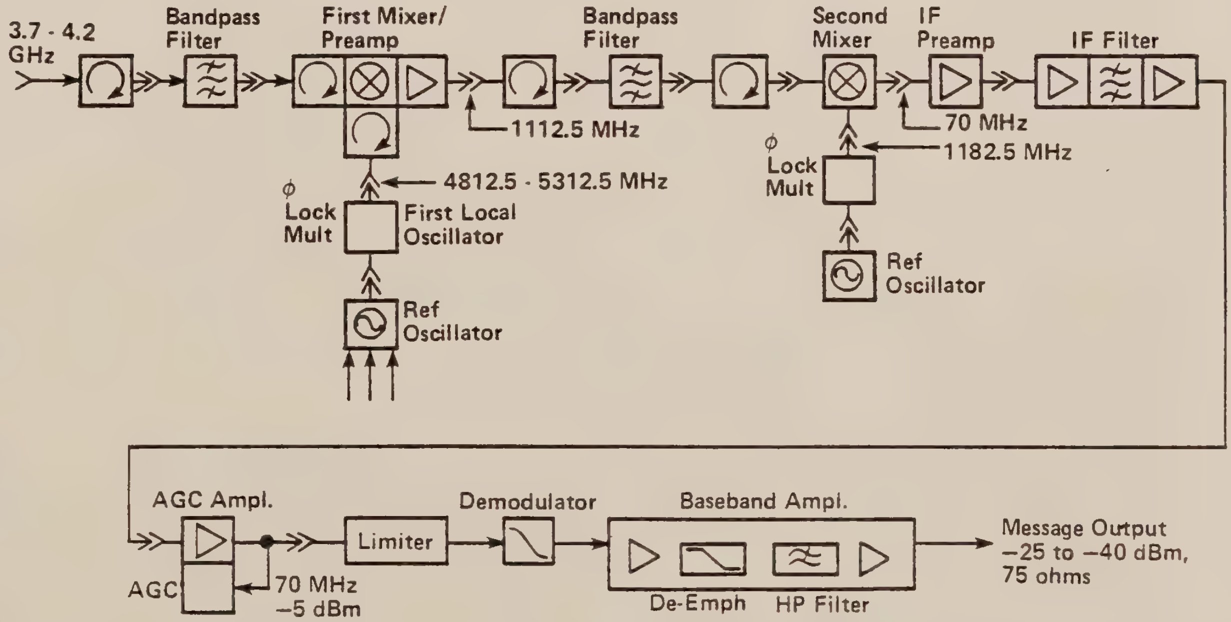



Figure 2-2. Dual-Conversion Message Receiver Block Diagram – Series 411.

## 411 RECEIVER MODULE TECHNICAL INFORMATION

**Series 411 Mainframe — Part No. 129106**

The mainframes for the receivers are standard 19 inch rack mounted designs that are 5.25 inches high. The mainframe is a U-shaped aluminum chassis with an integral rear panel that contains all input/output connections as well as ac power-line fuse. All operating controls are located on the front panel.

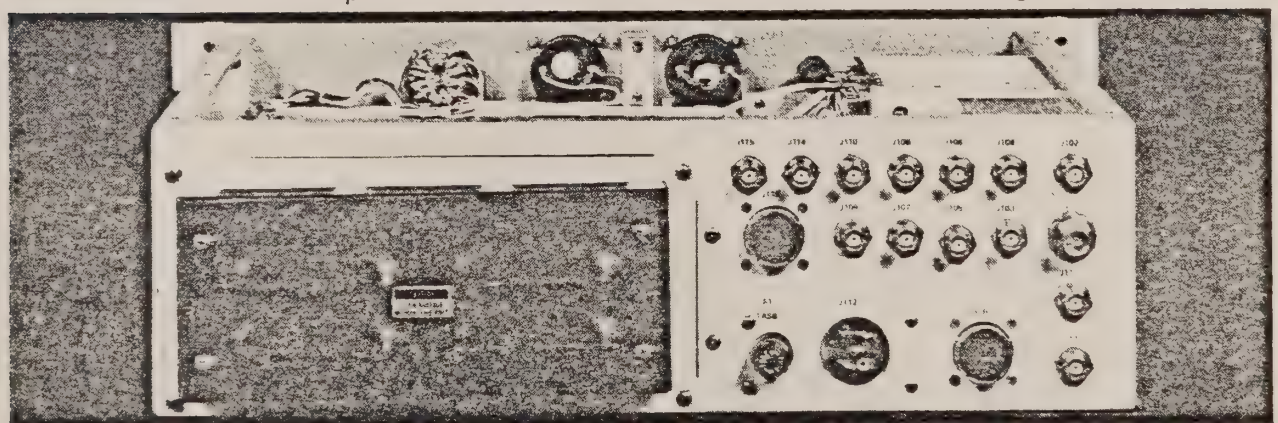
Internal wiring for all receiver configurations is identical. DC operating voltages are carried to the interface connectors of all modules, whether or not a module is inserted. Signal input and output interconnections are made via the rear-panel (see Photo No. 8489) connectors so that, with the appropriate external patch cables connected, the modules in any configuration will be properly interconnected. Rear panel patches are also furnished for such signals as the 70 MHz IF and first local oscillator to permit access to these signals for system testing and/or calibration.

The left hand section of the units is always reserved for the frequency converter which is a plug-in unit. The right section of the mainframe provides slide-in mounting facilities for the IF and baseband processing modules. Machined tracks in a plate at the bottom of the chassis guide the modules smoothly into position so they will positively mate with interface connectors on a bracket near the rear of the chassis. One important feature of Scientific-Atlanta's GCE is that the second slot from the right, with the mainframe viewed from the front, can be used as a test slot. The pins of the interface connector on the module plugged into the test slot are brought out to the rear of the chassis. In this way, the power supply can be used to power the module while it is under test. The unit may or may not be operational, however, under these conditions.

The Model 402A Power Supply is a plug-in unit that furnishes dc power to modules of the Scientific-Atlanta Series 400 Receiver equipment. Four voltages are produced: +24V dc, +12V dc, −24V dc, −12V dc. Current limiting is furnished for all four supplies; overvoltage protection in the form of a crowbar circuit is provided on the 12 volt supplies.

Ripple and noise on the output of the supplies is typically less than 10mV peak-to-peak for the 24 volt supplies, and 5mV peak-to-peak for the 12 volt supplies. Total load and line regulation for all supplies is typically less than 0.5%. This unit mounts on the rear apron of each chassis.

With regard to controls/metering of the receivers and exciters, the units have the power on/off control, a meter for signal level indication and a multi-function meter with associated function switch. The following tabulation provides the characteristics of the controls and metering.



Model 411WB Rear Panel, Photo 8489

| Control/Indicator | Position | Function |
|---|---|---|
| Power ON/OFF switch | ON (lit) | AC power applied to receiver |
| | OFF (dark) | AC power removed from receiver |
| METER FUNCTION switch | OFF | Meter disconnected |
| (Used in conjunction with multi-function meter next to switch) | −24 | Meter reads voltage on receiver −24V dc bus |
| | −20 | Meter reads output from −20V dc supply in downconverter (derived from receiver −24V dc bus) |
| | −12 | Meter reads voltage on receivre −12V dc bus |
| NOTE: Read voltages on top meter scale. | +12 | Meter reads voltage on receiver +12V dc bus |
| | DEMOD BB BB 1 BB 2 AUX 1 AUX 2 | These switch positions connect the meter to read various baseband and video levels at the outputs and inputs of the modules plugged into the mainframe. |
| CARRIER/NOISE meter | − − | Gives an indication of the ratio of carrier to noise. The meter actually reads (carrier + noise)/noise, and at very low carrier levels will read a little higher than the actual carrier level. At higher levels, however, noise contribution to the meter reading is insignificant. |

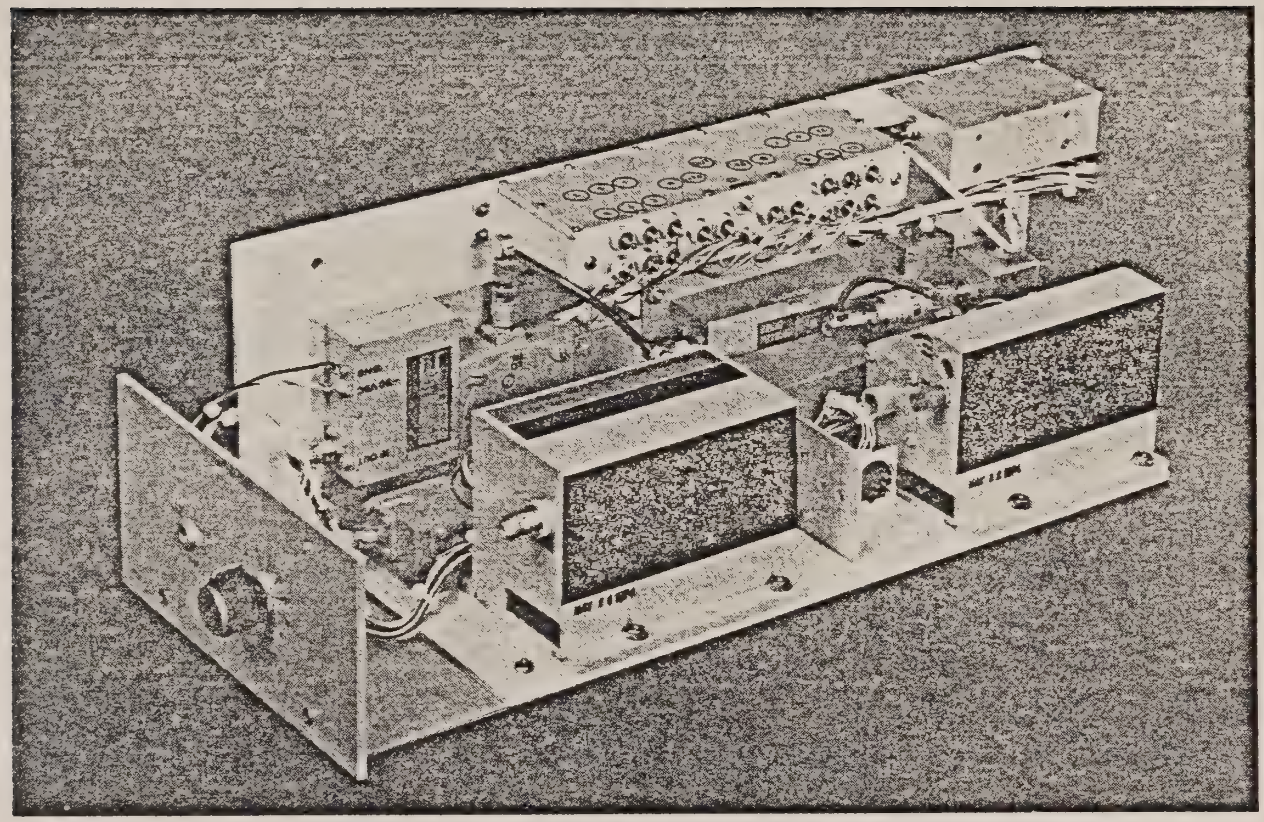
Table 1B. Receiver Mainframe Controls and Indicators

**Frequency Downconverter — Part No. 127235**

The downconverter to be utilized in the message and video receivers is Scientific-Atlanta's Standard Model 411WB(D) 3.7 - 4.2 - 0. This unit plugs into the mainframe in the extreme left hand position and receives its power from the mainframe.

The Model 411WB(D) 3.7 - 4.2 - 00 Downconverter is a dual conversion frequency agile unit that is utilized in Scientific-Atlanta's satellite communication message and video receivers. The input frequency is in the 3.7 - 4.2 GHz band and the output is a 70 MHz IF signal. The standard version has the capability of reception at any one of 12 switch-selectable frequencies. Remote Frequency selection is available as an option as well as a built-in frequency synthesizer. Photo No. 6632 shows the module which is held into the mainframe with four screws. RF connections to the downconverter are made on the rear panel of the mainframe. Also provided on the rear panel are the first LO signal and the main IF signal output. Patch cables furnished with the receiver complete the circuits for standard operation.

The function of the downconverter is to select the desired receive channel frequency and convert the incoming signal to an IF of 70 MHz. This is accomplished in two frequency conversions. The first conversion is to an IF of 1112.5 MHz. At this IF, signals are amplified, filtered, and then further converted to 70 MHz. Figure 2B is a functional block diagram.



**Model 411WB(D) 3.7 - 4.2 Downconvert Module, Photo 6632**

Signals entering the downconverter first pass through an input bandpass filter which has a passband from 3.7 - 4.2 GHz. It's function is to provide image rejection for the first conversion and rejection of out-of-band signals while passing all in-band received signals to the first mixer preamplifier unit. The mixer preamplifier selects the desired signal within the 3.7 to 4.2 GHz band according to the frequency supplied by the local oscillator and multiplier units.

The local oscillator provides frequencies from 4.81 to 5.31 GHz. The local oscillator frequency is determined by a switch-selectable crystal oscillator by an external source, or by an internal synthesizer.

The reference oscillator operates in the 100 to 110 MHz region and serves as as reference frequency for phase-locked multiplier. The multiplier provides a net frequency multiplication of 48 and provides sufficient power output in the 4.8 - 5.3 GHz range to drive the first mixer.

The desired signal ($f_o$) is selected by applying a local oscillator frequency of ($f_o$ + 1112.5) MHz to A1, which results in the desired signal being converted to an IF of 1112.5 MHz. The reference oscillator frequency is determined by the relationship:

$$F_{ref} = \frac{F_{rx} + 1112.5}{48}$$

After mixing and conversion to the 1st IF of 1112.5 MHz, a preamplifier in the mixer preamplifier assembly amplifies the signal and sets the noise figure of the downconverter.

Following the preamplifier the desired signal is filtered to a bandwidth of 40 MHz, which serves to suppress adjacent channel signals and provides image rejection for the second mixer. The second mixer provides the final conversion to the 70 MHz IF. The local oscillator for this conversion to 70 MHz, an output amplifier provides approximately 11 dB of gain at 70 MHz.

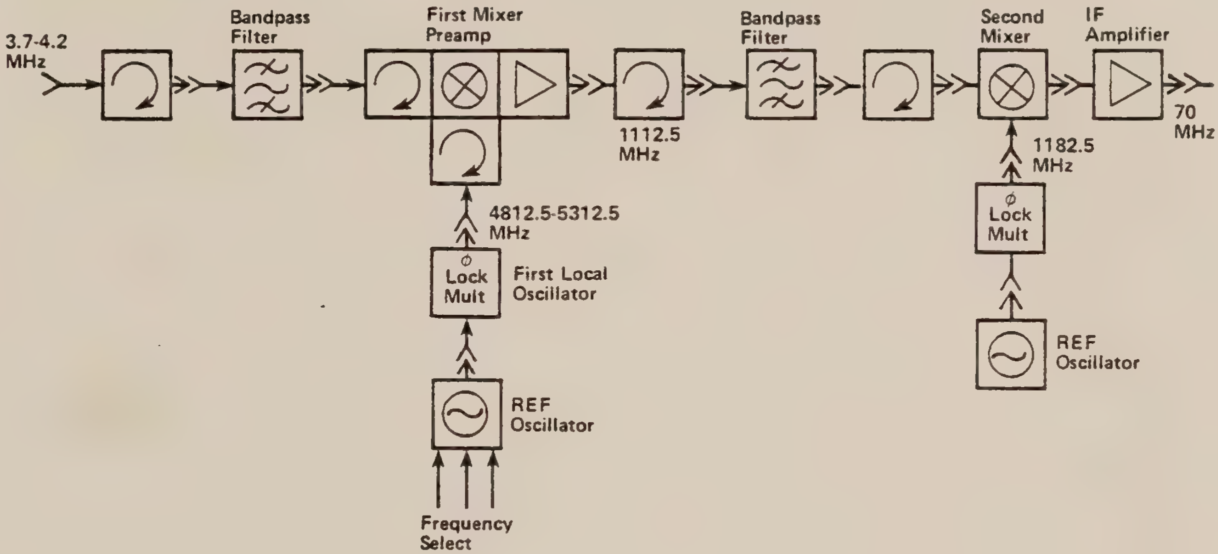



Figure 2B. Series 411 Dual Conversion Downconverter.

Figure 3B shows gain distribution in the downconverter.

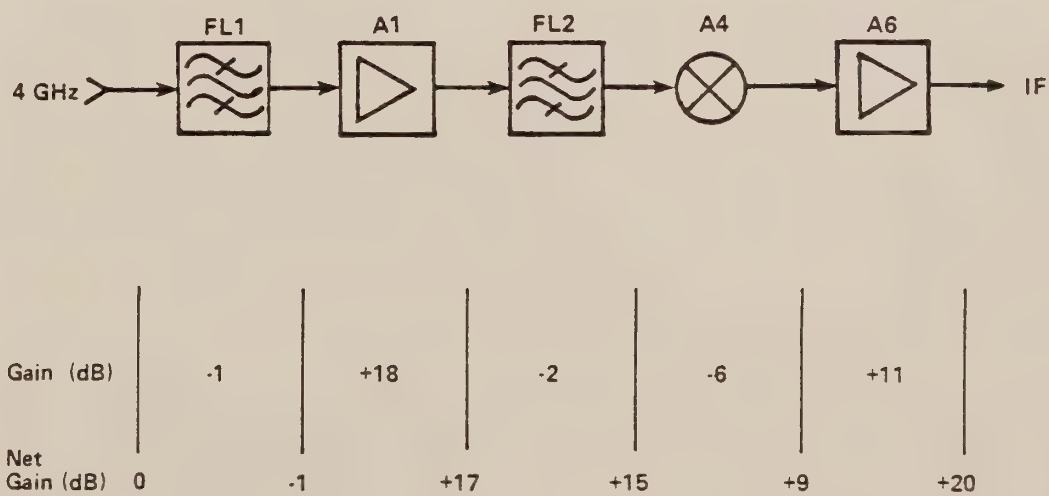



Figure 3B. Downconverter Gain Distribution.

All operating controls are provided on the front panel of the unit:

**Frequency Select** — The Frequency Select switch is used to select the frequency to be received. In the standard downconverter, the switch positions are marked 1 through 12. Refer to the Test Data section of this instruction manual for a cross reference from switch position to frequency.

**LO Select** — During normal operation, the LO Mode switch is left in the Local position, and the frequency of the 1st LO is determined by the front-panel Frequency Select switch. In the Remote position, 1st LO frequency is determined by an external source, external switch, or internal synthesizer.

- Input
  - Frequency
  - Level
    - 3700 to 4200 MHz
  - Impedance
    - −20 dBm max
  - Return Loss
    - 50 ohms
  - Noise Figure
    - 23 dB
    - 14 dB maximum, 12 dB typical
- Output
  - Frequency
  - Impedance
    - 70 MHz ±20 MHz
  - Return Loss
    - 75 ohms (unbalanced)
    - Greater than 23 dB from 50 MHz to 90 MHz
  - Image Attenuation
    - 80 dB minimum
  - Local Oscillator Leakage
    - −80 dBm maximum at RF input
  - RF-IF Gain
    - 20 dB nominal
  - Gain Response
    - ±0.25 dB, $f_o$ ±18 MHz
  - IF Bandwidth
    - 40 MHz, minimum
- Delay Distortion
  - Linear
    - Less than ±0.03 ns/MHz, $f_o$ ±18 MHz
  - Parabolic
    - Less than 0.01 ns/MHz$^2$, $f_o$ ±18 MHz
  - Ripple
    - Less than 1.0 ns peak-to-peak, $f_o$ ±18 MHz
- Third-Order Distortion
  - Greater than 50 dB below the desired carrier level when driven by two equal carriers at the RF input at −30 dBm each
- Spurious Responses
  - 65 dB below desired signal
- Local Oscillators
  - Standard
    - Frequencies
      - 12 Switchable
    - Stability
      - 1 part in $10^6$/day (25°C)
      - 2 parts in $10^7$/°C (0 - 50°C)
  - Optional
    - Frequencies
      - 1 to 12 as specified
    - Stability
      - ±200 Hz/day (15 - 35°C)

Table 2B. Downconverter Technical Characteristics.

**IF Filters** The IF Filters (see Photo No. 6623) are front plug-in modules for operation with the Series 411 Receivers and Series 461 Exciters. These units plug into specific slot assignments of the mainframe and receivers operating power from the mainframe power supply. Connections are made to the filter through an interface connector on the rear of the module.

The purpose of the filter is to provide rejection of unwanted out-of-band signals and to provide amplification of the desired in-band signals. In addition, equalization of group delay due to the filter is provided. The following is a block diagram of the IF filter.


Figure 4B. IF Filter Block Diagram.

The technical characteristics of the IF filters are listed in the following table:

Narrow Band Filters *

| BW (MHz) | Max Input Level | Receiver Gain | Exciter Gain |
|---|---|---|---|
| 2.5 | −24.6 dBm | 19.8 ±1 dB | 8 ±2 dB |
| 5.0 | −21.6 dBm | 16.6 ±1 dB | 8 ±2 dB |
| 7.5 | −19.8 dBm | 14.8 ±1 dB | 8 ±2 dB |
| 10 | −18.6 dBm | 13.6 ±1 dB | 8 ±2 dB |
| **Wideband Filters** | | | |
| 15.0 | −16.8 dBm | 11.8 ±1 dB | 8 ±2 dB |
| 17.5 | −16.1 dBm | 11.1 ±1 dB | 8 ±2 dB |
| 20.0 | −15.6 dBm | 10.6 ±1 dB | 8 ±2 dB |
| 25.0 | −14.6 dBm | 9.6 ±1 dB | 8 ±2 dB |
| 30.0 | −13.8 dBm | 8.8 ±1 dB | 8 ±2 dB |
| 36.0 | −13.0 dBm | 8.0 ±1 dB | 8 ±2 dB |

*1.25 MHz Bandwidth Filters are being added.

Table 3B. IF Filter Characteristics.

IF filter amplitude and delay characters are shown in Figures 5B and 6B.

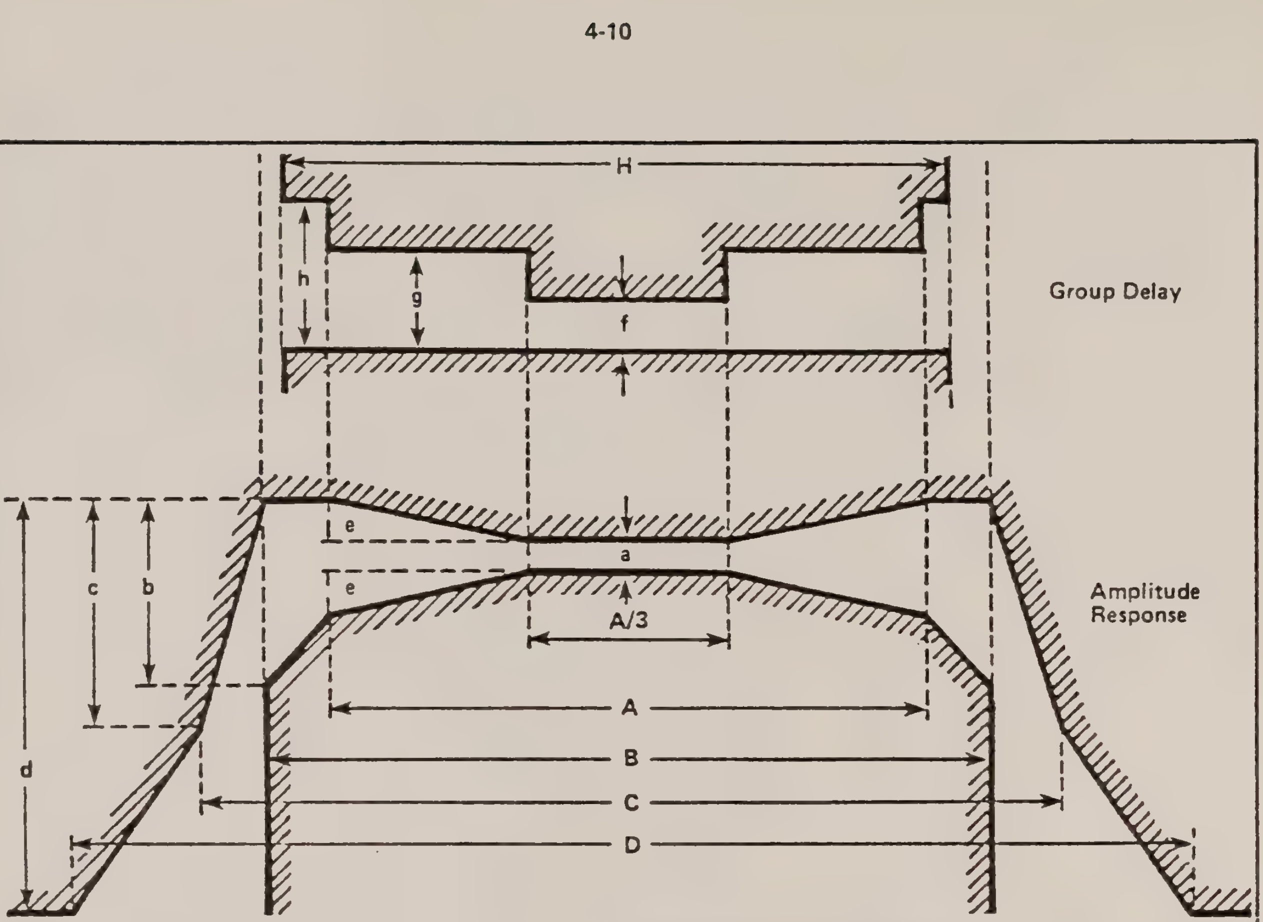



Figure 5B. IF Filter Amplitude-Delay Characteristics.

| S-A Part No | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131621 | 2.5 | 1.8 | 2.25 | 2.75 | 8.0 | 0.7 | 1.5 | 2.5 | 25 | 0 | 2.1 | 16 | 16 | 20 |
| 131622 | 5 | 3.6 | 4.5 | 5.25 | 13.0 | 0.5 | 2.0 | 3.0 | 25 | 0 | 4.1 | 12 | 12 | 20 |
| 131623 | 7.5 | 5.4 | 6.75 | 7.75 | 17.0 | 0.4 | 2.5 | 4.0 | 25 | 0 | 6.2 | 12 | 12 | 20 |
| 131624 | 10 | 7.2 | 9.0 | 10.25 | 19.0 | 0.3 | 2.5 | 5.0 | 25 | 0.1 | 8.3 | 9 | 9 | 18 |

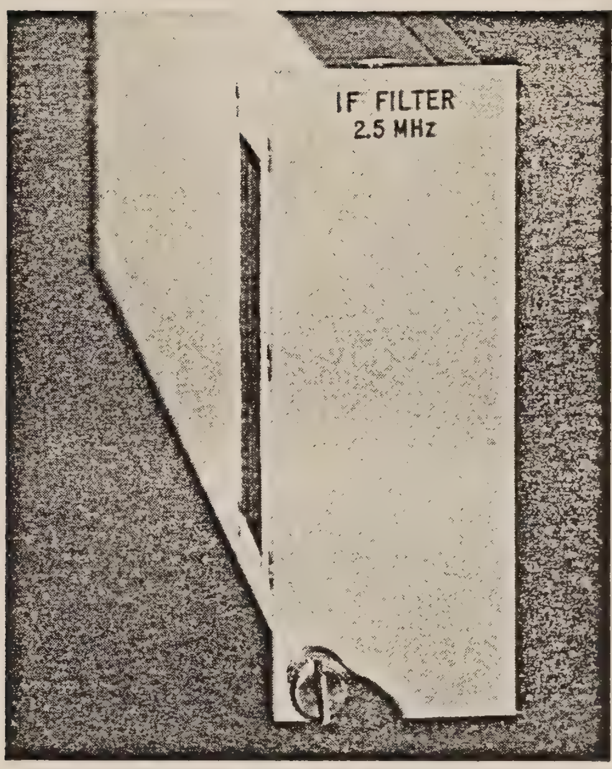
| S-A Part No. | BW (MHz) | A (MHz) | B (MHz) | C (MHz) | D (MHz) | a (dB) | b (dB) | c (dB) | d (dB) | e (dB) | H (MHz) | f (ns) | g (ns) | h (ns) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131625 | 15 | 10.8 | 13.5 | 15.5 | 25.0 | 0.3 | 2.5 | 5.5 | 25 | 0.1 | 12.4 | 6 | 6 | 15 |
| 131626 | 17.5 | 12.6 | 15.75 | 18 | 26.5 | 0.3 | 2.5 | 6.5 | 25 | 0.1 | 14.2 | 6 | 6 | 15 |
| 131627 | 20 | 14.4 | 18.0 | 20.5 | 28.0 | 0.3 | 2.5 | 7.5 | 25 | 0.1 | 16.6 | 4 | 5 | 15 |
| 131628 | 25 | 18.0 | 22.5 | 25.75 | 34.0 | 0.3 | 2.5 | 8.0 | 25 | 0.2 | 20.7 | 3 | 5 | 15 |
| 131930 | 36.0 | 28.8 | 36.0 | 45.25 | 60.0 | 0.6 | 2.5 | 10.0 | 25 | 0.3 | 33.1 | 3 | 5 | 15 |
| 131929 | 30 (video) | 24.0 | 30.0 | – | – | 0.5 | 2.5 | – | – | 0.3 | 30.0 | 5 | 5 | 15 |

Figure 5. Amplitude-Delay Characteristics.

**IF Amplifier – Part No. 127183**

The IF amplifier (see Photo No. 6622) is a front panel plug-in module for utilization in the Series 411 Receivers. The unit is all solid-state and receives its operating power from the mainframe assembly.

The purpose of the IF amplifier is to provide signal amplification at the IF frequency of 70 MHz and to provide automatic gain control of the signal. This feature presents a constant 70 MHz input level to the circuits that follow. A block diagram of the IF amplifier is shown in Figure 7B.




IF Filter Module, Photo 6623

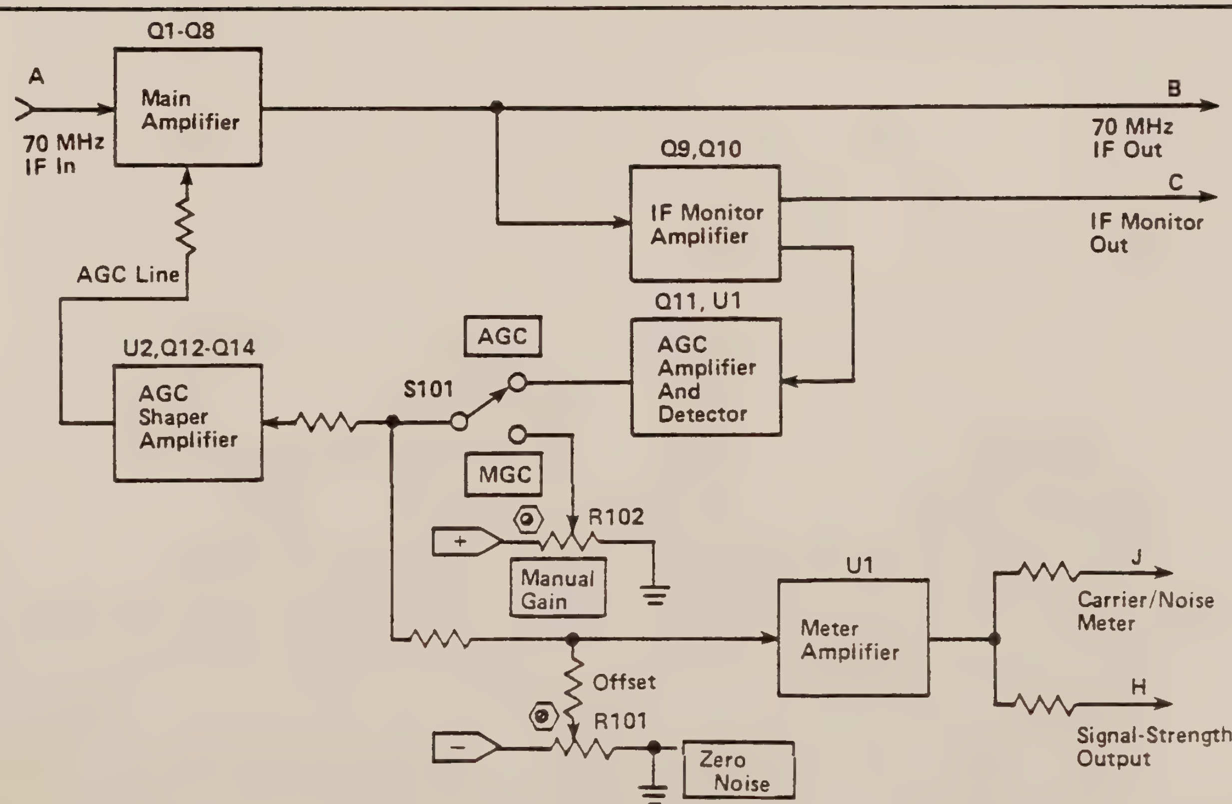
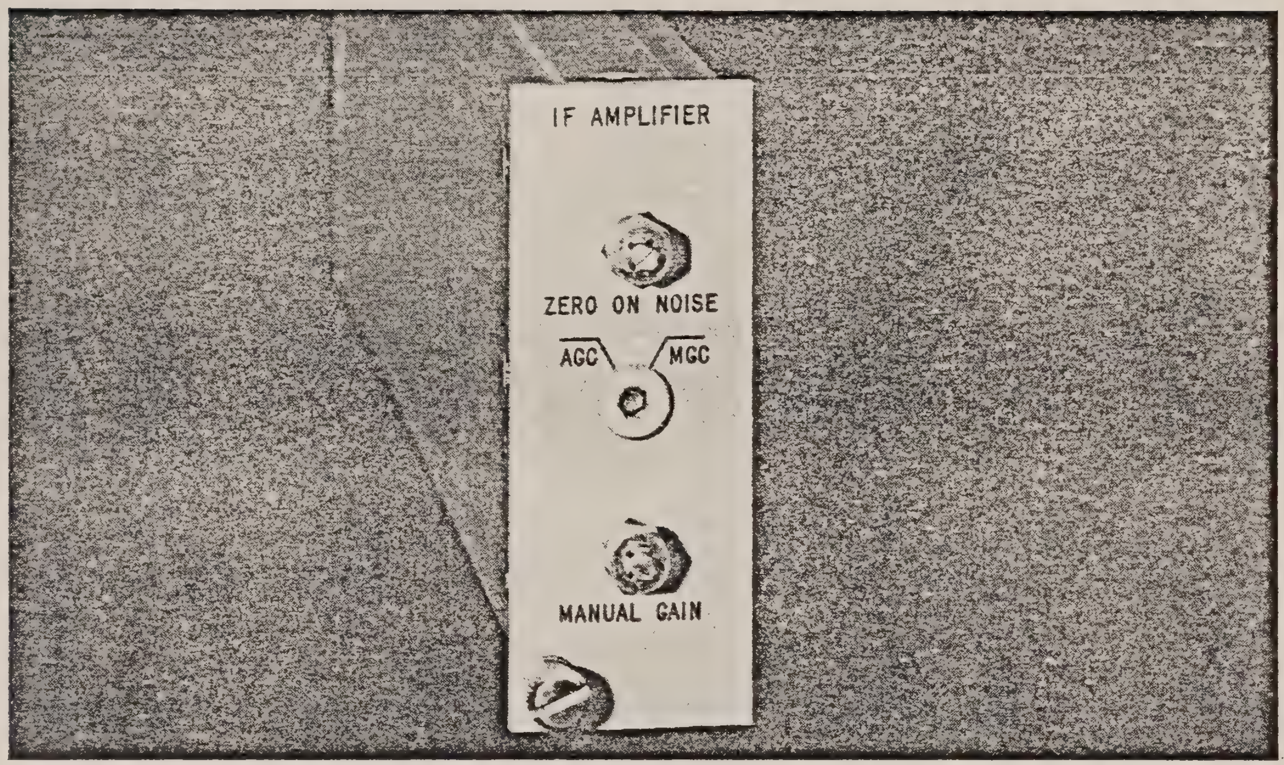



Figure 7B. IF Amplifier Block Diagram.




**IF Amplifier Module, Photo 6622**

The following table provides the overall technical characteristics.

**Input**
- Frequency
  - 70 ±20 MHz
- Impedance
  - 75 ohms unbalanced
- Return Loss
  - >23 dB
- Level
  - −5 dBm max

**Output**
- Impedance
  - 75 ohms unbalanced
- Return Loss
  - >20 dB
- Level
  - −5 dBm (with AGC)

**Gain**
- AGC or MGC
  - 0 to +40 dB
- Flatness
  - 0.5 dB peak-to-peak

**Group Delay**
- <0.5 ns variation

**Monitor Output**
- Impedance
  - 75 ohms unbalanced
- Return Loss
  - <20 dB
- Level
  - Within 1 dB of main output

Table 4B. IF Amplifier Technical Characteristics.

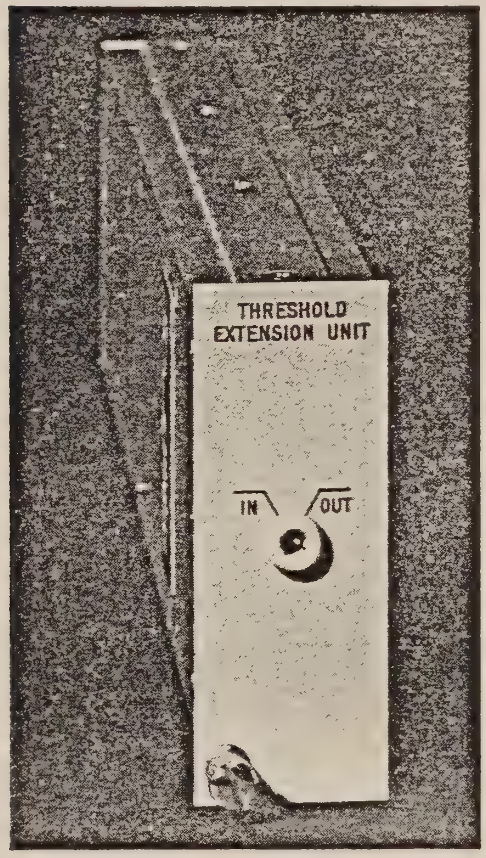
**Threshold Extension Unit – Part No. 141423**

The threshold extension unit (Photo No. 6694) is a plug-in module intended for operation with Scientific-Atlanta Series 411 Receiver Equipment. When used with Scientific-Atlanta's message demodulator (Part No. 131675), it provides extension of the demodulator threshold point when low C/N levels are obtained. Channel capacity changes are easily made by changing the loop-filter board internal to the TEU.

Active circuits of the threshold extension unit are contained on two circuit boards. One contains the circuits of the loop filter and plugs into the second, which is a mother board attached to the left side of the module. Input and output connections are made through an interface connector on the rear of the module.

The single control on the TEU is a screwdriver-operated switch that allows the threshold extension circuits to be disabled (OUT position), thereby allowing the TEU to operate as a conventional limiter. The normal operating position is in the IN position.

The design of this threshold extension unit is highly proprietary and specific details on its design and technique of threshold extension have been omitted.




Threshold Extension Unit, Photo 6694

## THRESHOLD EXTENSION UNIT TECHNICAL CHARACTERISTICS

| Characteristic | Specification |
|---|---|
| IF Center Frequency | 70 MHz |
| Return Loss | 75 ohms |
| Input | >20 dB (70 ±10 MHz) |
| Output | >20 dB (70 ±10 MHz) |
| IF Limiting | 20 dB Nominal |

| Channel Capacity* | Loop Filter Part Number |
|---|---|
| 12 | 141424 |
| 24 | 141425 |
| 36 | 141426 |
| 48 | 141427 |
| 60 | 141428 |
| 72 | 141429 |
| 84 | 141430 |
| 96 | 141431 |
| 108 | 141432 |
| 120 | 141433 |
| 132 | 141434 |
| 144 | 141435 |
| 180 | 141436 |
| 192 | 141437 |
| 252 | 141438 |

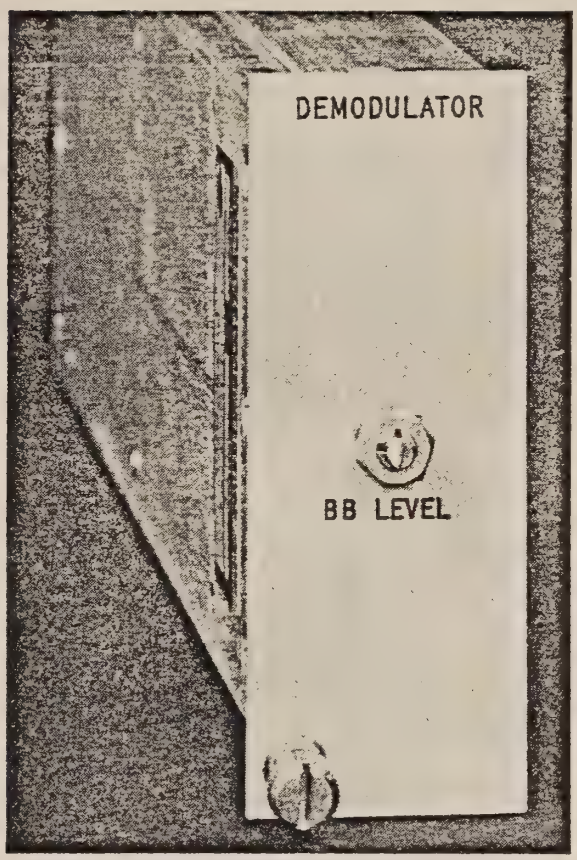
*Threshold Extension Units up to 432 channels are also available.

**Wideband FM Decmodulator – Part No. 131675**

The purpose of the wideband demodulator is to recover wideband FM information and provide a multiplexed baseband signal at a −25 dBm level at the test tone frequency for 12 to 1872 channel message formats and 1 volt peak-to-peak signal at the test tone frequency for all video formats.

The wideband FM demodulator (Photo No. 8327) is a plug-in module intended for operation with Scientific-Atlanta Series 411 Receiver equipment. The demodulator provides discrimination of wideband frequency-modulated signals, and is specifically designed for use in satellite communications for both message (12 to 1872 channels) and video (all formats) reception. Below 600 channels, a threshold extension unit (Part No. 131615) may be used in conjunction with the demodulator.

Front-panel potentiometer R201 controls the final level out of the demodulator. Q20 is a peak detector which can be used to determine approximate video output levels as noted on the mainframe multifunction meter. The peak detector does not respond to message signals.

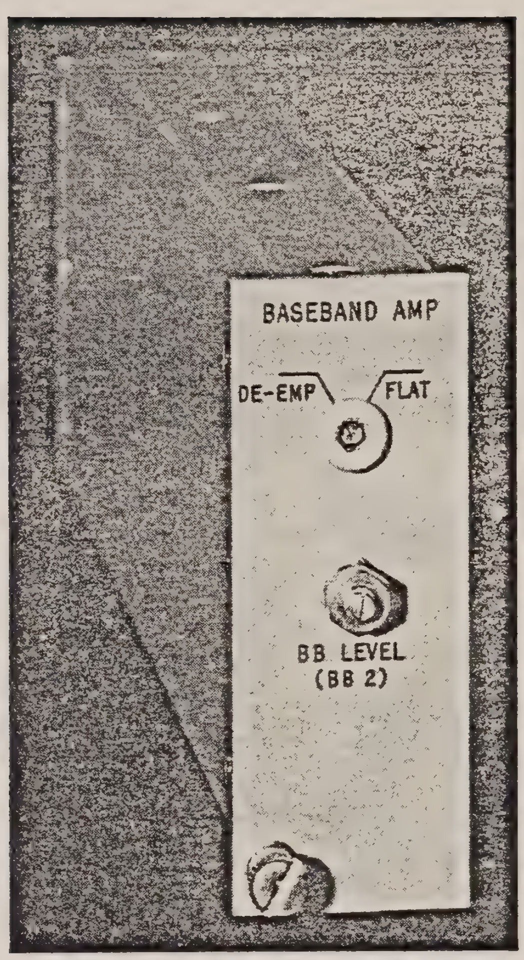



Wideband Demodulator, Photo 8327

Type
FM
IF Center Frequency
70 MHz
Input Impedance
75 ohms
Input Return Loss (70 ± 18 MHz)
>26 dB
IF Limiting
15 dB minimum
IF Input Level
−5 dBm ±2 dB

Discriminator Linearity (70 ± 18 MHz)
Better than 1%
Output Level
Message
−25 dBm at test tone (TT) Deviation
Video
1.0V peak-to-peak at TT frequency
Frequency Response
±0.1 dB (15 Hz to 6 MHz)
±0.2 dB (6 MHz to 8.2 MHz)

Table 5B. Wideband FM Demodulator Technical Characteristics.




Receiver Baseband Amplifier Module, Photo 6621

**Baseband Amplifier (Message Receiver).** Baseband amplifier (see Photo No. 6621) is a dual purpose module that plugs into the front panel of the receiver mainframe. Unit contains the de-emphasis networks and a 3 kHz highpass filter for the energy dispersal waveform removal as well as furnishing a minimum of 10 dB of baseband amplification. Unit contains four separate modules which plug into a mother board. The board provides the interconnection between the modules and connections to the front and rear panels. The internal modules consist of two amplifiers, one high-pass filter module, and one de-emphasis board. Figure 2-30 is a block diagram of the unit. Channel capacity is easily changed by the simple replacement of the de-emphasis board. A complete listing of the standard capacities is shown in the following tabulation:

DE-EMPHASIS BOARDS (Per CCIR Rec 275-2 and BG28-72E)

| Channel Capacity | fm (kHz) | Part Number |
|---|---|---|
| 12 | 60 | TBD |
| 24 | 108 | 131705 |
| 36 | 156 | 131706 |
| 60 | 252 | 131707 |
| 72 | 300 | 131708 |
| 96 | 408 | 131709 |
| 132 | 552 | 131710 |
| 192 | 804 | 131711 |
| 252 | 1052 | 131712 |
| 312 | 1300 | 131713 |
| 432 | 1796 | 131714 |
| 612 | 2540 | 131715 |
| 792 | 3284 | 131716 |
| 972 | 4028 | 131717 |
| 1092 | 4892 | 131718 |
| 1872 | 8120 | 131719 |

Baseband signal first passes through a variable attenuator which controls the signal level out of the receive baseband amplifier. A series capacitor serves as a dc block for the incoming signal so that any dc offset voltage out of a previous module will not affect the dc output level of the amplifier. After being amplified the signal then passes through either the de-emphasis network (with the front-panel switch in the DE-EMP) or a 4 dB attenuator (with the front panel switch in the FLAT position). Normal operating position is the DE-EMP position with the FLAT position typically used only for testing purposes. Signal then passes through a 4 pole Butterworth high pass active filter with a nominal 3 dB frequency of 3 kHz. This filter rejects the energy dispersal frequency and all its harmonics. Signal is then capacitively coupled to the output amplifier module which is the final gain block.

Plug-in amplifiers are dc coupled with a flat frequency response to approximately 10 MHz. Both amplifiers operate in the non-inverting configuration. A potentiometer is included to set the dc output level with no input signal.

De-emphasis boards consist of a de-emphasis network which meets the requirements of CCIR Recommendation 275-2 and BG28-72E. Input and output impedance is 75 ohms. In addition there is a 4 dB, 75 ohm, attenuator (which is the approximate loss of the de-emphasis network at the de-emphasis crossover frequency) which is switched in when the entire receive baseband amplifier is tested for flatness.

The following controls are located on the front panel of the module:

| | |
|---|---|
| DE-EMP/FLAT Switch | Screw driver operated switch which switches in the de-emphasis network (DE-EMP) or a 4 dB attenuator (FLAT). The normal operating position is DE-EMP. |
| BB-LEVEL (BB2) | Locking potentiometer which adjusts the output level. This is a set-up control and should not require readjustment once a system has been set up. |

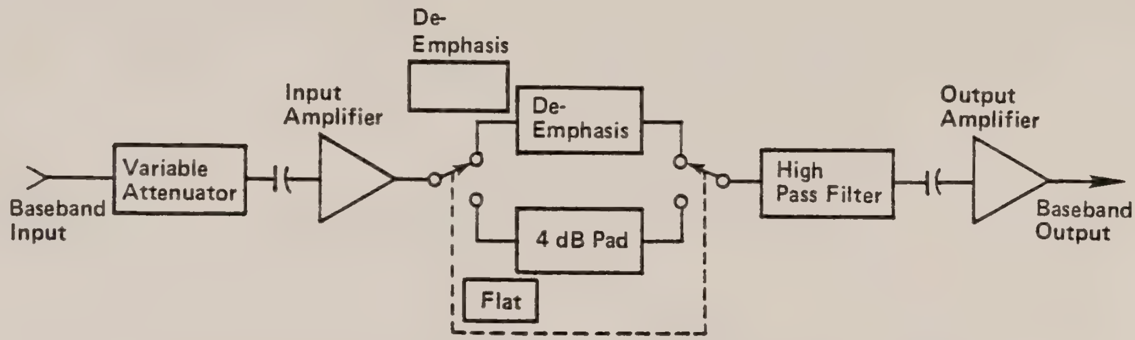



Figure 2-30. Message Receiver Baseband Amplifier Block Diagram.

SUMMARY TECHNICAL CHARACTERISTICS

Input/Output Impedance Gain
- 75 ohms
- 10 dB minimum

Frequency Response
- 4 - 12 kHz
  - 0.4 dB
- 12 kHz - 8.2 MHz
  - 0.1 dB
- 12 kHz - maximum frequency (de-emphasis)
  - 0.2 dB

**Pilot/Noise Monitor Module – Part No. 131680**

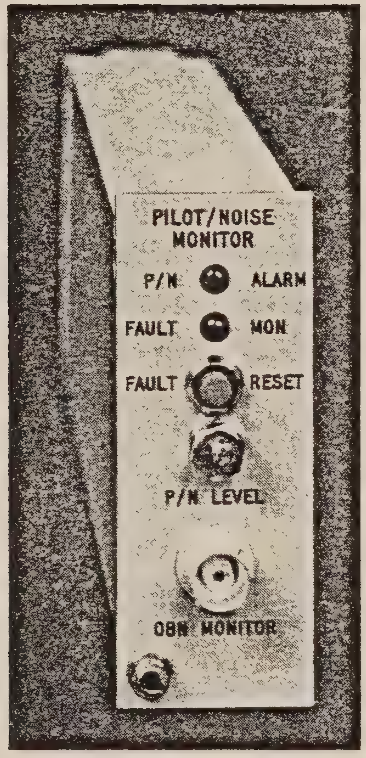
The pilot/Noise monitor is a front panel plug-in module for utilization with the Series 411 Receivers. Module monitors five receive functions and generates an alarm signal when any out-of-tolerance condition exists. These five functions are:

a. First LO Phase Lock
b. Second LO Phase Lock
c. Receiver AGC (C/N)
d. 60 kHz Pilot Level
e. OBN Noise Level

When connected in an IF to baseband string functions "a" and "b" are disabled. A fault of any one of the above provides local indication by turning on an LED fault indicator. In addition to the front panel indication, the P/N module provides two signals for use by external circuits for remote indications or switchover logic. These are a relay contact closure and an open collector output for a voltage indication. Once a fault has occurred, the LED fault indicator will remain illuminated until the reset button has been depressed; however, the alarm indicator will clear automatically when the fault is cleared. The following table lists the alarm functions and associated alarm levels.

## PILOT/NOISE MONITOR MODULE TECHNICAL CHARACTERISTICS

Function
  Receiver alarm indication and signalling
Receiver Functions monitored
  1st LO phase lock
  2nd LO phase lock
  60 kHz pilot/noise
  Noise
1st LO Phase Lock Alarm
  Upon loss of −12V dc from 1st LO in downconverter
2nd LO Phase Lock Alarm
  Upon receipt of phase-lock-loop search signal (60 Hz triangle wave) from 2nd LO in down-converter (typically 18 volt peak-to-peak sawtooth waveform)




Pilot/Noise Monitor, Photo 8148

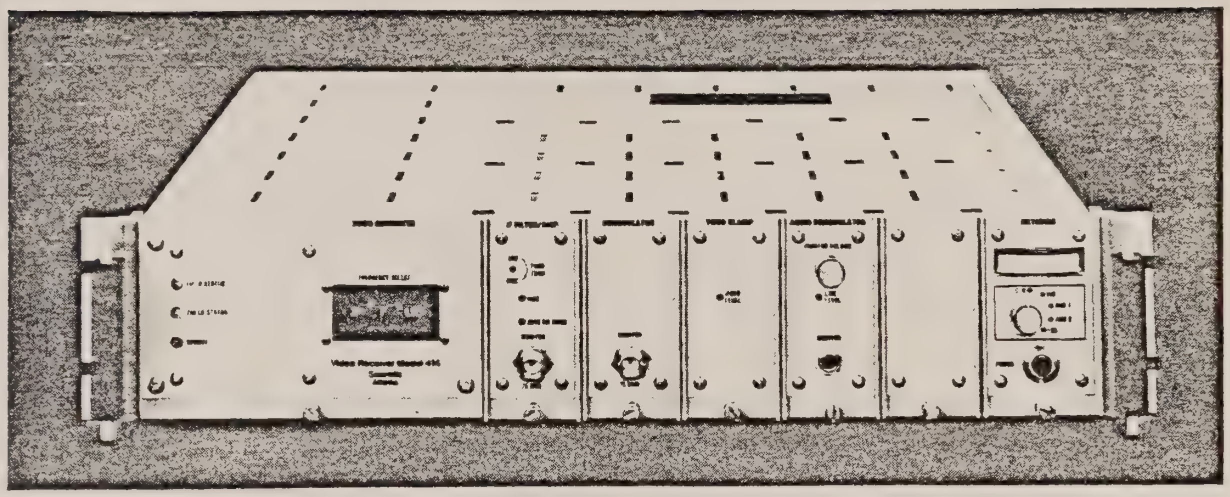
# THE MODEL 414 RECEIVER

Written By:
Heinz Wegener
Edited By:
Edward J. Chapman
Manager, GCE Engineering
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978



## SCIENTIFIC-ATLANTA'S 414 RECEIVER

**Introduction** *Scientific-Atlanta recognized the need for a modular, flexible video receiver several years ago and developed the 411 receiver. However, it was not until several years after the development of the 411 receiver that domestic satellite transmission of video was being used to the extent it is today. For this reason the 411 receiver evolved from a video receiver into a multipurpose satellite communications receiver that is presently used worldwide and domestically to process any video or message format being transmitted.*

*As the domestic video market began to realize its full potential, Scientific-Atlanta felt that a receiver designed specifically for video was again required and this is the 414 Video Receiver. The 414 Video Receiver has been designed with the following features:*

*A. Utilization of field proven circuitry used in the 411 to the greatest extent possible.*
*B. Modularity to allow easy field repair.*
*C. Ease of operation by minimizing controls.*
*D. Utilization of common types of interface connectors to allow the most convenient interconnection between the receiver and external equipment.*
*E. Synthesizer controlled frequency selection to obtain crystal controlled frequency accuracy without the need for individual crystals for each frequency.*
*F. An option plug-in position to allow expansion to stereo, over-the-air frequency selection, additional program channels or any other transmission that requires an additional audio demodulator.*
*G. Ease in trouble-shooting by bringing out 5 isolated monitor connectors and providing level indications of final outputs.*
*H. Local/Remote/Automatic Frequency selection modes which greatly simplify 1:N back-up schemes as well as over-the-air frequency selection.*
*I. Two video outputs to allow monitoring of the final video signal.*
*J. A 3½-inch panel height allows more receivers to be placed in a rack.*
*K. 115/230 Volt AC power supply with optional -24 or -48V DC supplies.*

**Block Diagram Discussion**

*Scientific-Atlanta's Model 414 Video Receiver together with an antenna and low noise pre-amplifier combine to form a complete satellite video receive terminal providing a video and audio output signal. The 414 Receiver accepts the incoming 3.7 to 4.2 GHz signal, converts it to an IF signal and demodulates it to provide an output video and audio signal for distribution. Figure 7 is a block diagram of the receiver.*

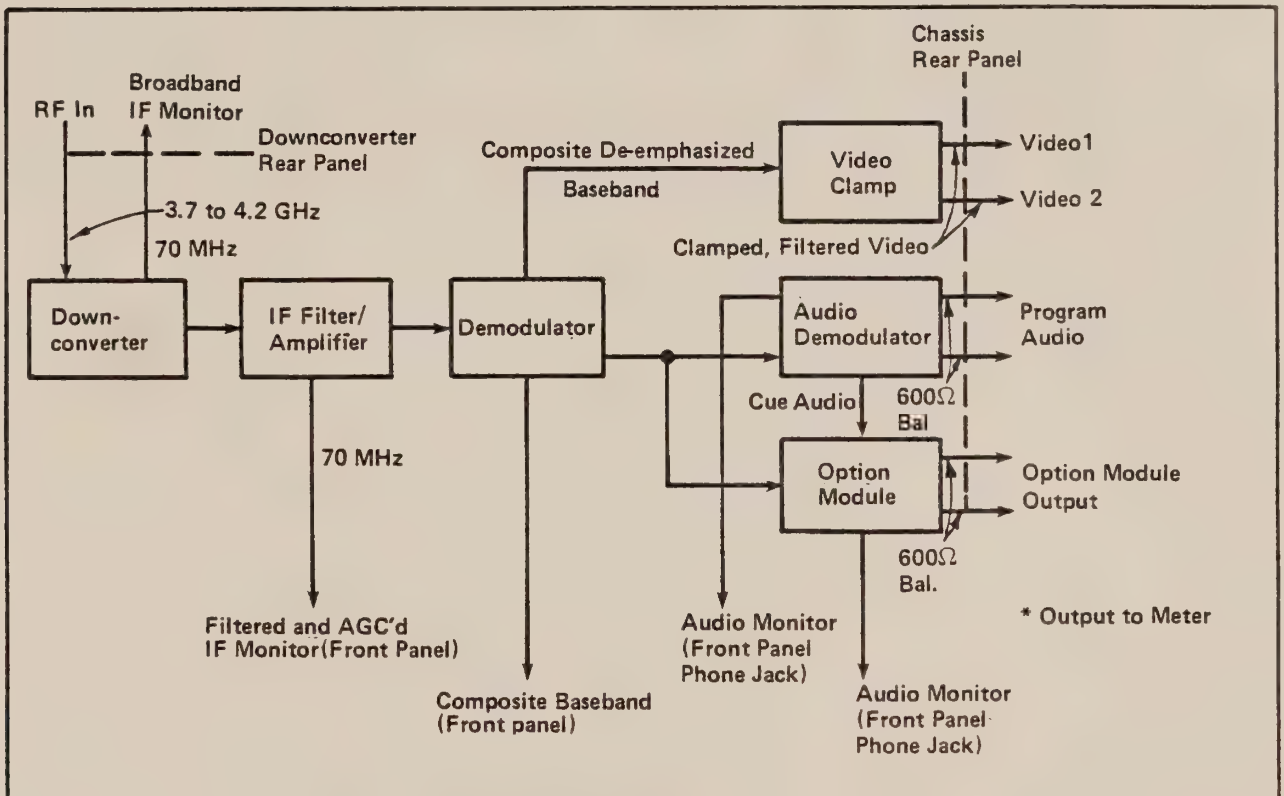



Figure 7. Model 414 Video Receiver Block Diagram.

*The dual conversion downconverter of the Model 414 Video Receiver accepts an input signal in the 3700 MHz to 4200 MHz range and converts it, in the two mixing stages, to an IF of 70 MHz.*

*The first mixer stage has an output frequency of 880 MHz which is reduced in the second mixer stage to the receiver's second intermediate frequency of 70 MHz. Frequency selection is provided by the synthesizer, which controls the local oscillator frequency of the first mixer stage. The synthesizer's frequency is set with the front panel thumbwheel switches, or by an external signal if remote frequency control has been selected.*

*An isolated 70 MHz IF output on the rear of the downconverter allows monitoring the broadband IF signal out of the downconverter. This monitor point has a 75 ohm impedance and is at a level nominally 20 dB higher than the incoming RF signal.*

*Filtering and amplification stages in the downconverter refine the 70 MHz IF signal before it goes into the receivers second module, the IF filter/amplifier.*

*This unit has, as its name implies, two basic functions, the rejection of unwanted out-of-band signals and the amplification of signals in the desired passband. The automatic gain control (AGC) enables the IF filter/amplifier to maintain the 70 MHz signal at a constant level at its output even though the strength of the incoming RF signal may vary. The gain control can be operated manually for testing purposes or obtaining highly accurate C/N measurements using a power meter. The AGC circuit also provides a DC voltage to drive the front panel meter when the carrier-to-noise ratio (C/N) function is selected on the metering module.*

*An isolated, filtered, and AGC'd output on the front panel of the IF Filter/Amplifier allows monitoring the signal out of the unit. The impedance of this monitor point is 75 ohms and the nominal level is –5 dBm in the AGC position. If future applications require a different IF bandwidth then the IF Filter/Amplifier would be replaced with one of the new IF bandwidths.*

*The 70 MHz IF output from the IF Filter/Amplifier is the input to the demodulator module. Limiting circuits in the demodulator remove AM components from the FM signal. Demodulation of the video signal and de-emphasis for either 525-line or 625-line broadcast are also accomplished in this unit. The demodulator outputs are composite baseband (BB) signals containing the video and audio information and the dispersal waveform. One of these outputs goes to the video clamp and one to the audio demodulator positions.*

*The signal going to the audio demodulator positions has a guaranteed flatness from 4 to 8 MHz. An isolated output on the demodulator front panel allows monitoring the composite signal entering the video clamp. The impedance of this monitor point is 75 ohms and the nominal level is 1 volt peak-to-peak.*

*In the video clamp, the subcarrier and the energy dispersal waveform are removed from the video signal and the dc level is restored. The clamp has two video outputs, each suitable for either distribution or monitoring of the video signal.*

*Level detection of the output video is accomplished using a sync tip level detector. This allows accurate video level settings independent of the average picture level (APL) of the video signal. A voltage proportional to the level of the sync tips is directed to the metering module which indicates the level of the video signal.*

*The audio demodulator rejects all frequencies in the composite video signal except the subcarrier, which contains the audio information. The audio signal is then demodulated, filtered, de-emphasized and amplified to provide the program audio output. An additional output from this module becomes the input for the optional cue demodulator.*

*A phone jack on the front panel allows monitoring the output audio using standard 8 ohm headphones.*

*The option module is intended to be either a cue demodulator or a second audio demodulator, however, with special mainframe wiring other features may be incorporated. When a cue demodulator is used in this position, input*

*is a single-sideband, suppressed-carrier signal from an audio demodulator. Output is a filtered and amplified audio signal suitable for cue transmission.*

*The power supply for the Model 414 - also modular, but accessible from the rear of the receiver - distributes +20 volts and -20 volts to each module in the receiver. Regulators inside each module convert the supplies into the required operating voltages (±15 volts for most modules).*

*Sample outputs from several modules are routed to the metering module so that receiver operation can be evaluated. The multi-function meter can monitor C/N, the ±20-volt supplies, and output levels of the video and audio signals. The ac power switch is also on this module.*

**Technical Characteristics** *Technical characteristics of the Model 414 Video Receiver are listed in Table 1-1.*

| | |
|---|---|
| **RF Input** | **Video Output** |
| Maximum Level | Level |
| *-33 dBm* | *1V p-p ±3 dB adjustable* |
| Frequency | Frequency Response (RF to BB) |
| *3700 - 4200 MHz* | *15 Hz to 4.2 MHz ±.30 dB* |
| Impedance | Impedance |
| *50 ohms* | *75 ohms unbalanced* |
| Return Loss | Return Loss |
| *≥20 dB* | *30 dB* |
| Noise Figure | Polarity |
| *15 dB maximum* | *Black to white: positive-going* |
| Frequency Agility | **Clamping** |
| *Frequency synthesizer with increments of 2.5 MHz* | *40 dB dispersal rejection* |
| | **Distortions** |
| RF Input Dynamic Range | Differential Phase |
| *40 dB* | *(10-90% APL) ±0.5°* |
| Video IF Bandwidth | Differential Gain |
| *17.5 to 36 MHz* | *(10-90% APL) ±2.0%* |
| **Deviation Range** | Line-Time Waveform Distortion |
| *5 to 12 MHz peak at de-emphasis cross-over frequency* | *1% tilt maximum* |
| | Field-Time Waveform Distortion |
| **De-Emphasis** | *1% tilt maximum* |
| *525L or 625L CCIR Rec. 405-1, as required.* | **Program Output** |
| | Frequency Response |
| | *50 Hz to 15 kHz ±.5 dB* |
| | Level |
| | *0 dBm to 10 dBm for test tone deviation at the test tone frequency* |
| | Impedance |
| | *600 ohms balanced* |

Table 2. Video Receiver Technical Characteristics

*Figure 8 shows a front view of the 414 receiver highlighting its features. Figure 9 and Table 3 give rear panel information.*

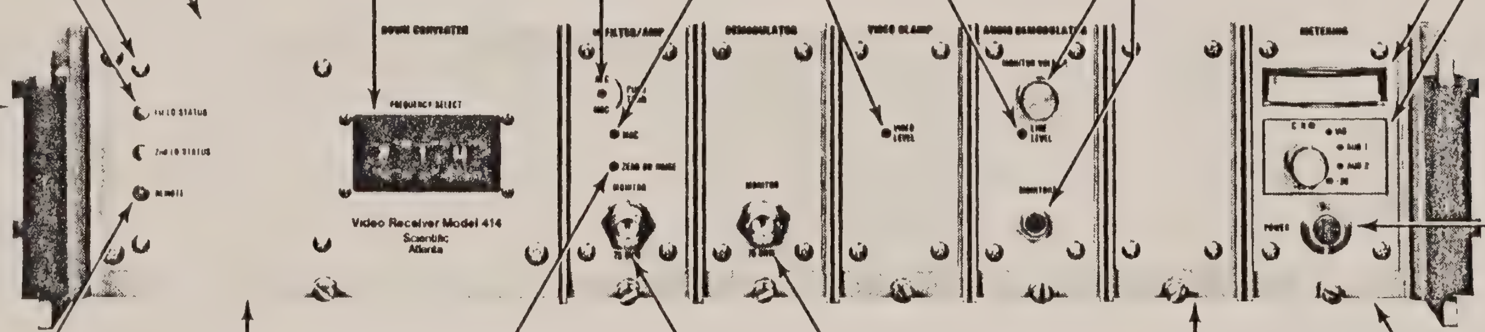
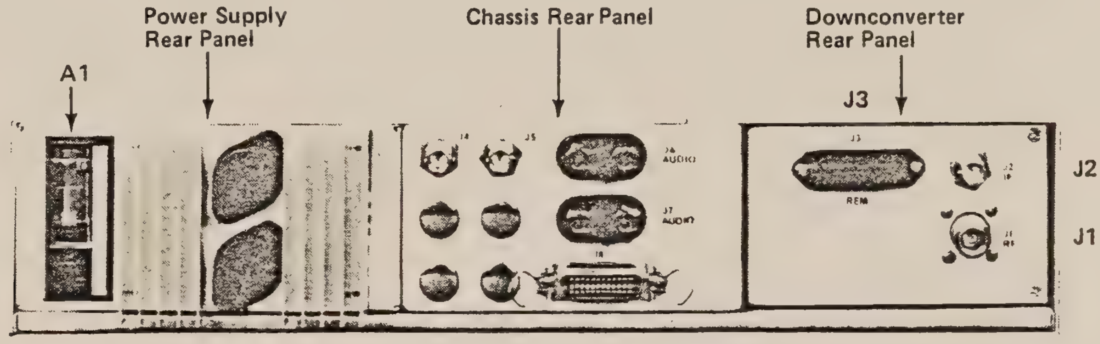



Figure 8. Front View of the 414 Receiver Highlighting Features.

*Figure 9 and Table 3 give rear panel information.*




| | | | |
|---|---|---|---|
| J1 | Type N female, 50 ohms | J6, J7 | Dual banana jacks |
| J2 | BNC female, 75 ohms | J8 | 24 pin, female |
| J3 | 24 Pin, female | J9-J12 | Spares |
| J4, J5 | BNC female, 75 ohms | A1 | Ac line connector and Fuse Assembly |

Figure 9. 414 Video Receiver Rear Panel with Callouts for Input & Output Connectors.

| Connector Designator | Function |
|---|---|
| J1 | RF Input |
| J2 | Broadband IF Monitor |
| J3 | Inputs for remote frequency - selection signals |
| J4 | Video Output 1 |
| J5 | Video Output 2 |
| J6 | Program Audio Output |
| J7 | Option Module Audio Output |
| J8 | Metering and Alarm Connections |
| J9 | Spare |
| J10 | Spare |
| J11 | Spare |
| J12 | Spare |

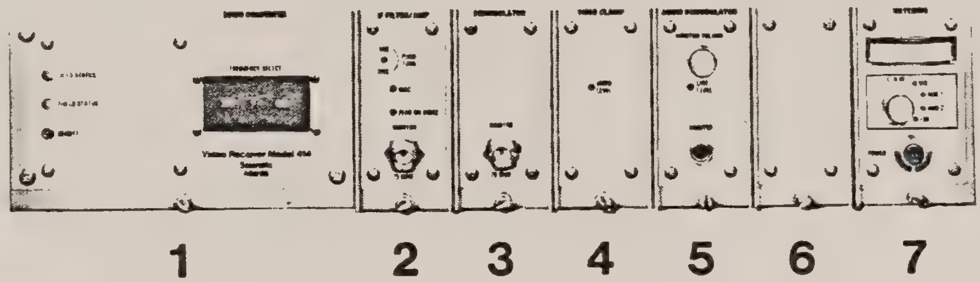
Table 3. Input/Output Connectors

**Automatic/ Local/Remote Switch**

*The Automatic/Local/Remote switch, inside the downconverter, is initially set at the time of installation but may be reset at the operator's discretion. It controls the operating mode of the receiver as follows:*

a. *When the switch is in the Local position, frequency selection can only be made by the front panel thumbwheel switches.*
b. *When the switch is in the Remote position, frequency selection can only be made by an external signal. In most applications this signal will come from a Scientific-Atlanta Series 400 Automatic Protection Switch.*
c. *When the switch is in the Automatic position, frequency selection will normally be controlled by the front panel thumbwheel switches. However, in this mode, the protection switch can override the manual controls by applying a ground signal to the automatic frequency pin, switching the receiver to remote operation.*

**Equipment Options** *Several different versions of the Model 414 Video Receiver are available to fill our customer's varying needs. Please contact your Scientific-Atlanta sales representative for details of these options and others that may become available.*




STANDARD MODULES

1. Downconverter
2. IF Filter/Amplifier
   *Available in several filter bandwidths*
3. Demodulator
   *Available for 525 line or 625 line operation, with or without threshold extension*
4. Video Clamp
5. Audio Demodulator
   *Available for 6.8 MHz or 6.2 MHz subcarrier with 5 kHz, 10 kHz, or 15 kHz audio bandpass*
6. Blank
   *Audio Demodulator*
   *Cue Demodulator*
7. Metering
   *Alarm Module*
   ** Power supply, -19V to -26V dc input*
   ** Power supply, -42V to -54V dc input*

Figure 10. Model 414 Video Receiver Configurations.

**414 Checkout Plan** *All modules are individually checked out before they are put into the receiver. The entire receiver is then burned in for approximately 1-2 weeks to reduce the probability of "infant" mortalities. After this burn-in period, receiver tests are run to check gain, gain/frequency response, group delay, and all video tests. A 72-hour 50° C burn-in is also completed on each receiver.*

**414 Maintenance Requirements** *The only required maintenance on the 414 receiver is periodic video and audio output level checks.*

# SERIES 6600 VIDEO RECEIVERS

James A. Hart
Project Manager
Cable Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## SERIES 6600 VIDEO RECEIVERS

### 1.0 Introduction

The increased employment of video receivers in geostationary satellite microwave links during the past year has been phenominal. High volume applications of electronic equipment make possible design and production techniques which lead to decreased production time and costs. The benefit to the user is lower prices with equal performance to the predecessors. The Series 6600 radios have achieved these goals. The design approach has also led to simple plug-in replacement of printed circuit cards for field repair and additional services in the future.

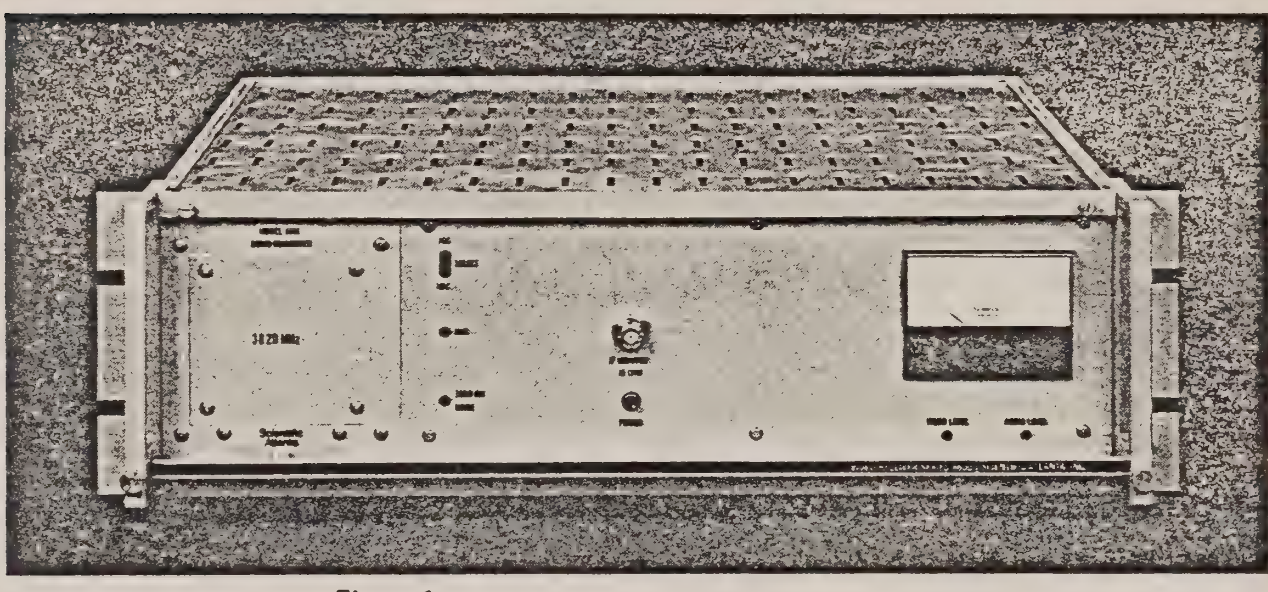


Figure 1.

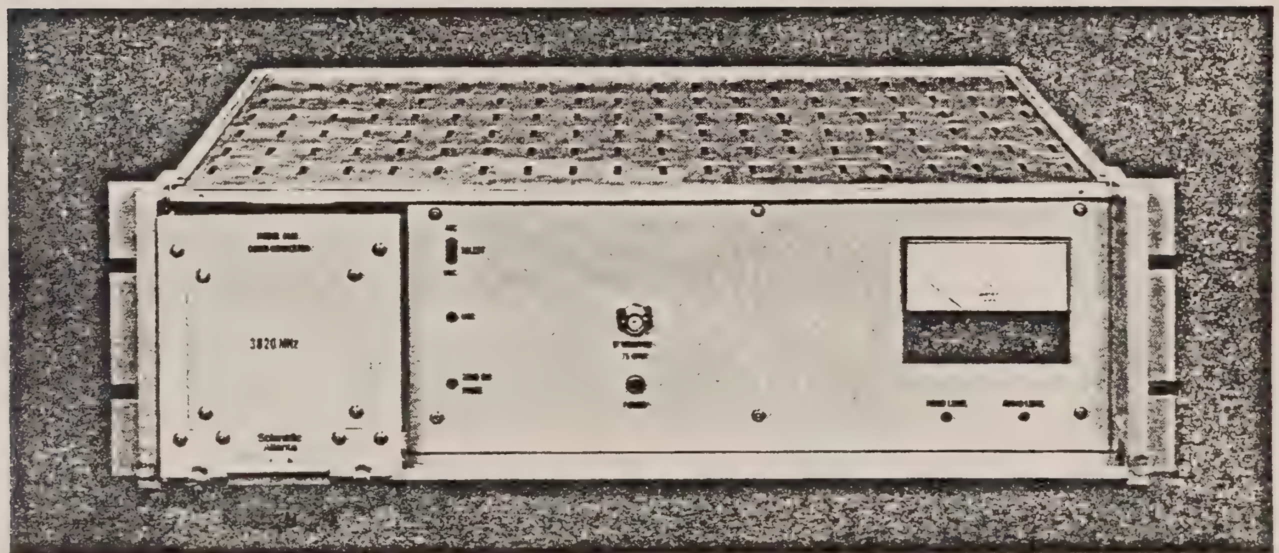


Figure 2.

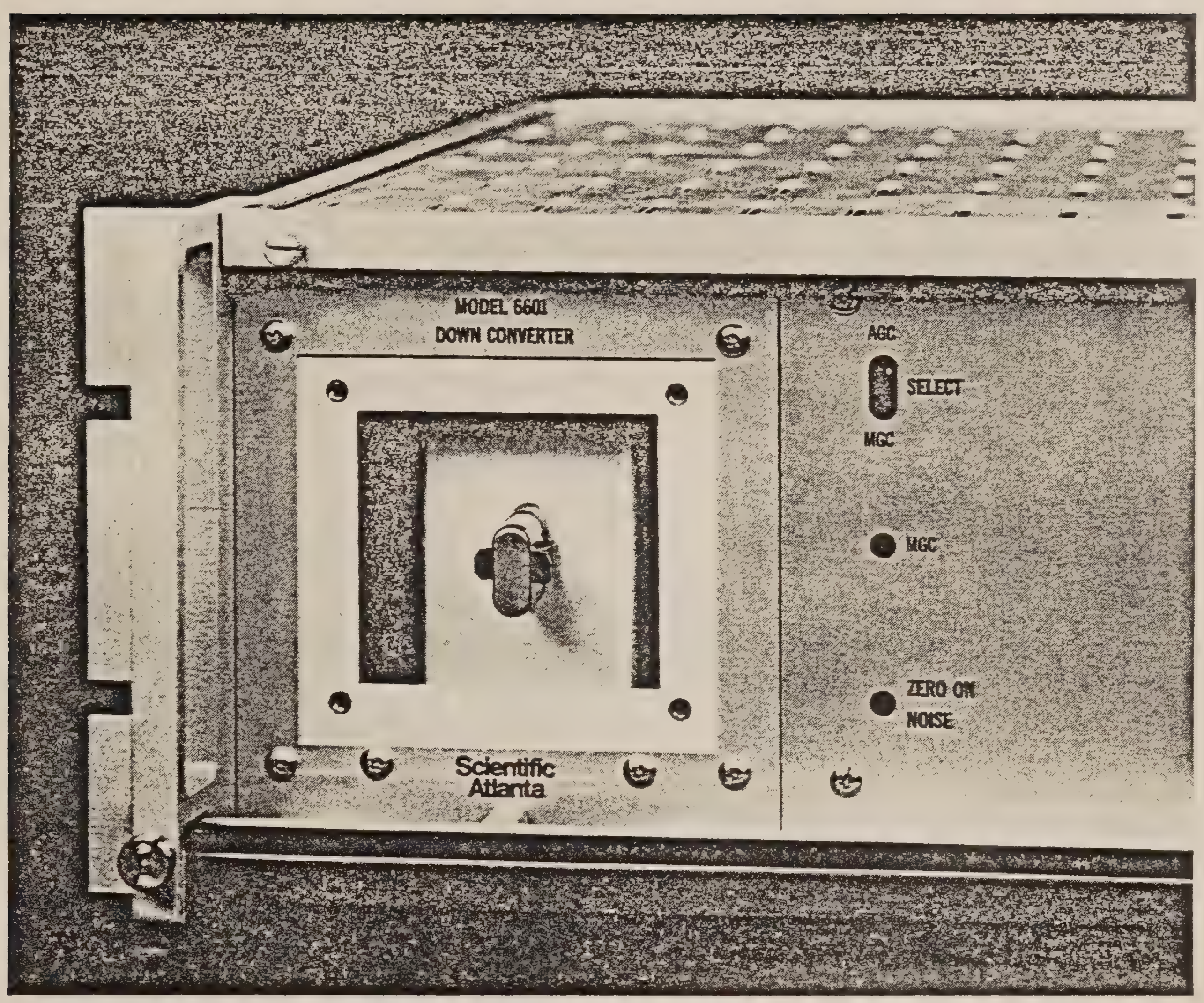



Figure 3.

**2.0 Design Approach**

Figure 1 is a photograph of the Series 6600. The design approach provides modular downconverters and power supplies. The downconverters plug in from the front of the radio as shown in Figure 2. Easy access to the crystal or frequency determining switches and removal of the downconverter is possible from the front panel as shown in Figure 3.

The power supply is packaged in a rugged module removable from the rear panel by four screws and a single connector.

The IF, video demodulator, clamp, audio demodulator, and three auxiliary modules are plug-in printed cards connected by a single large interconnecting printed card. Interconnecting cards make equipment more reproducible and lead to low production costs. Access to the card cage is accomplished by removal of two knurled decorative front panel screws and a slide-in top cover. Figure 4 is a photograph of the receiver and its card cage.

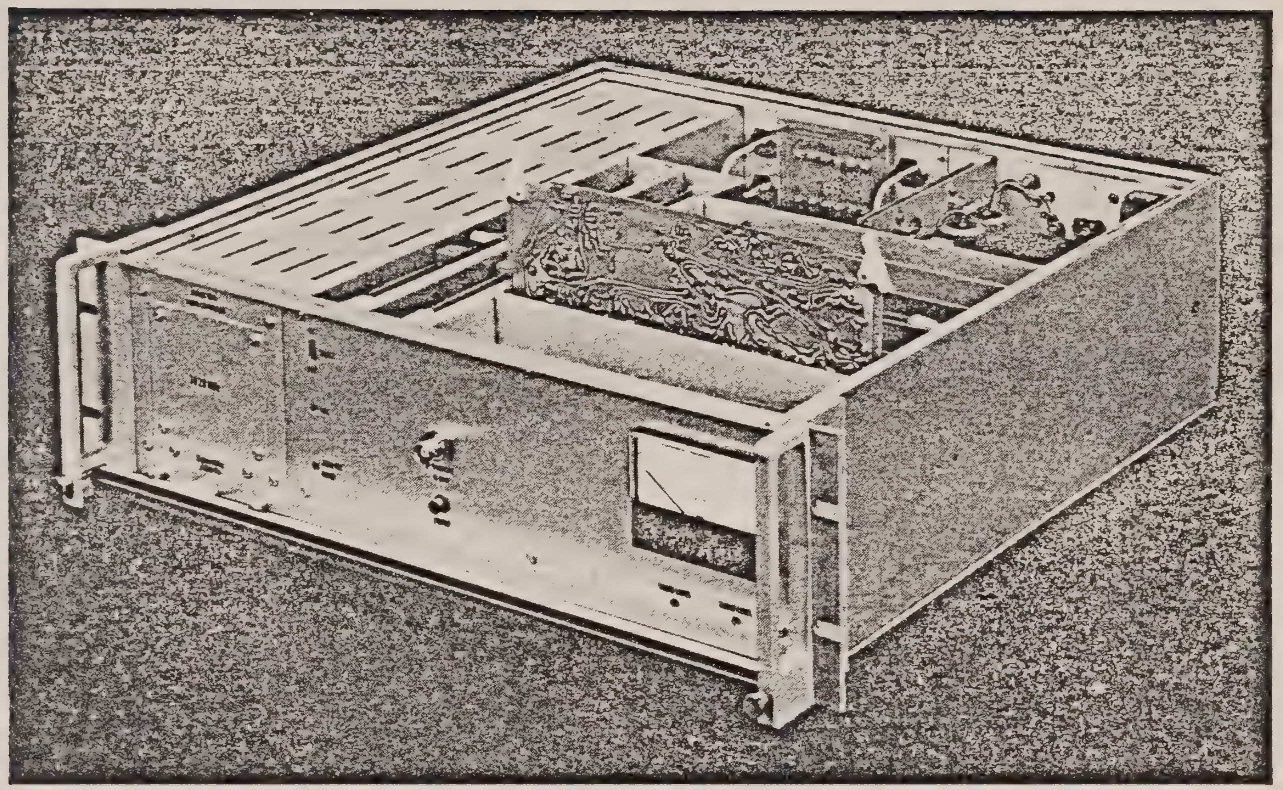


**Figure 4.**

A standard power module operates from 115V ac 60 Hz. An optional power module is offered for −24V dc sources.

Two downconverters are offered. A single channel converter whose receive frequency is determined by a single crystal is the basic unit. A second unit provides 24 channel synthesis of the local oscillator. A switch on the front panel or 5V logic on the rear of the radio determine the received channel.

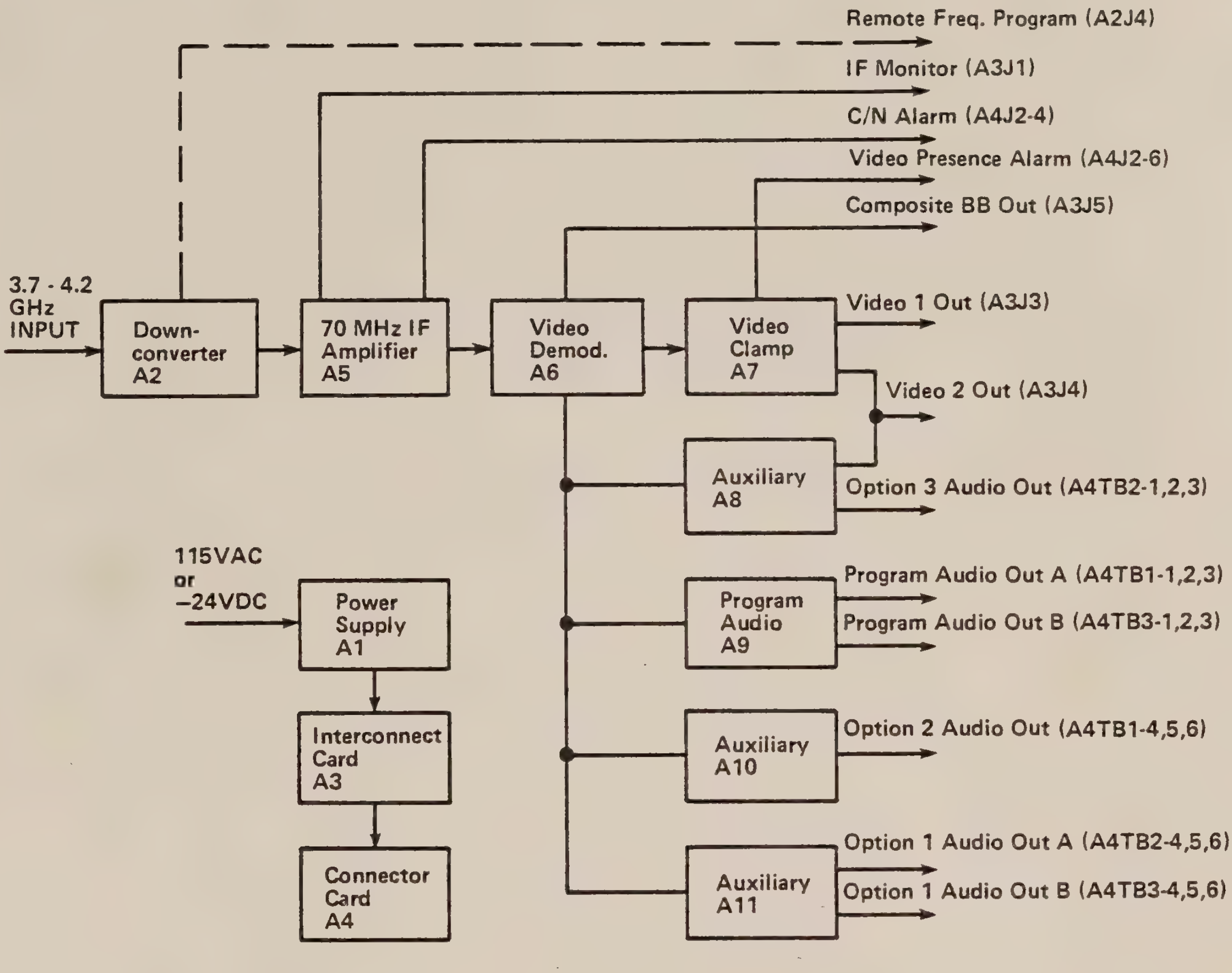



Figure 5. Series 6600 Video Receiver Block Diagram

**3.0 General Description** Figure 5 is a block diagram of the Series 6600 receivers. Model 6601 consists of the main frame with a single channel downconverter, and Model 6602 is the same mainframe with the agile downconverter. The 115V ac power module is standard with –24V dc as an option.

**3.1 Downconversion** The input 3.7 - 4.2 GHz signal is first converted to an 880 MHz IF frequency by an integrated microwave front-end. The IF bandwidth is approximately 80 MHz. A second converter module in the downconverter heterodynes this 880 IF down to 70 MHz. The bandwidth of the 70 MHz IF as it leaves the downconverter via an interconnecting cable on the rear remains approximately 80 MHz. The center frequency of the IF is determined by the crystal frequency in the Model 6601 and by the synthesized local oscillator frequency in the Model 6602. Channel frequencies are 3720 MHz to 4180 MHz in 20 MHz steps –24 channels total.

**3.2 IF Amplifier** The downconverter 70 MHz IF output connects to IF Amplifier Module A5 located in the card cage via an interconnecting cable. The IF amplifier contains five pole-pair filter sections and a single section delay equalizer. An AGC loop maintains an IF output of –5 dBm over a 40 dB input dynamic range. The IF noise bandwidth is 32.4 MHz nominal. The IF output can be observed on the front panel at an IF MONITOR port. This port is useful in accurate measurement of C/N with a 75 ohm power meter. Access to an AGC/MAN switch on the IF card is provided through clearance holes in the front panel. Also a MGC control is provided for setting gain in the manual mode. Another control is provided on the front panel for zeroing the C/N meter on noise in a normal AGC mode of operation. This latter control must be set with the entire system in normal operation. Adjustment of the ZERO ON NOISE control depends on EIRP, antenna gain, LNA gain, cable losses, and the receiver gain in front of the IF output. The C/N meter provides easy monitoring of carrier-to-noise for day-to-day monitoring.

**3.3 Demodulation** Demodulation of the 70 MHz IF occurs in Video Demodulator Module A6. This card contains a limiter, discriminator, de-emphasis, output drivers, and Scientific-Atlanta's patented threshold extension. The demodulator card drives all subcarrier cards, the clamp, and a COMPOSITE BB connector on the rear panel. This monitor port has video baseband, all subcarriers, and energy dispersal as demodulated from the IF carrier.

**3.4 Clamping** The Video Clamp Module A7 contains a roofing filter which removes the subcarriers and a clamp which provides 40 dB of dispersal rejection. Video output level is adjustable on the front panel. Two video outputs are provided on the rear panel. A video alarm circuit provides –1 to –5 volts dc when video is present and 0 to –0.2 volts dc when video is absent. The source impedance is 220 ohms on this alarm output.

**3.5 Audio** Program Audio Module A9 demodulates the 6.8 MHz audio subcarrier and provides two balanced 600 ohm outputs on the rear. Audio level is adjustable from the front panel. The subcarrier filter is approximately 500 kHz wide. The output roofing filter is a 15 kHz low-pass type.

**3.6. Auxiliary Modules** Auxiliary Module A8 can be utilized for one of two functions. A card which modulates the audio out of A9 onto a 4.5 MHz subcarrier and adds this carrier to Video Output 2 can be provided in this position. Microwave systems can be driven direct from the radio without an additional external audio modulator. An audio demodulator can also be placed in this position for demodulation of additional subcarriers. One balanced 600 ohm output is provided on the rear panel from this position.

Auxiliary Modules A10 and A11 provide two additional slots for audio subcarrier demodulators. Module A10 provides a single 600 ohm output while A11 provides two 600 ohm outputs. Modules A8, A10, A11 together provide for 3 subcarrier demodulators in addition to program audio (A9).

Additional links on the interconnecting card between A8, A9, A10, and A11 permit pilot carriers from the Program Audio Module to be demodulated. Queing and remote receiver control may be added in the future.

**4.0 Specifications** Table 1 is a preliminary listing of Series 6600 specifications. As compared to most overall link specifications, it can be seen that the receiver is relatively transparent.

Figure 6 gives the threshold performance of the Series 6600 receivers. The demodulator operates without threshold extension down to a C/N of 12 dB. Threshold extension is automatically switched in at a C/N of 12 dB and below.

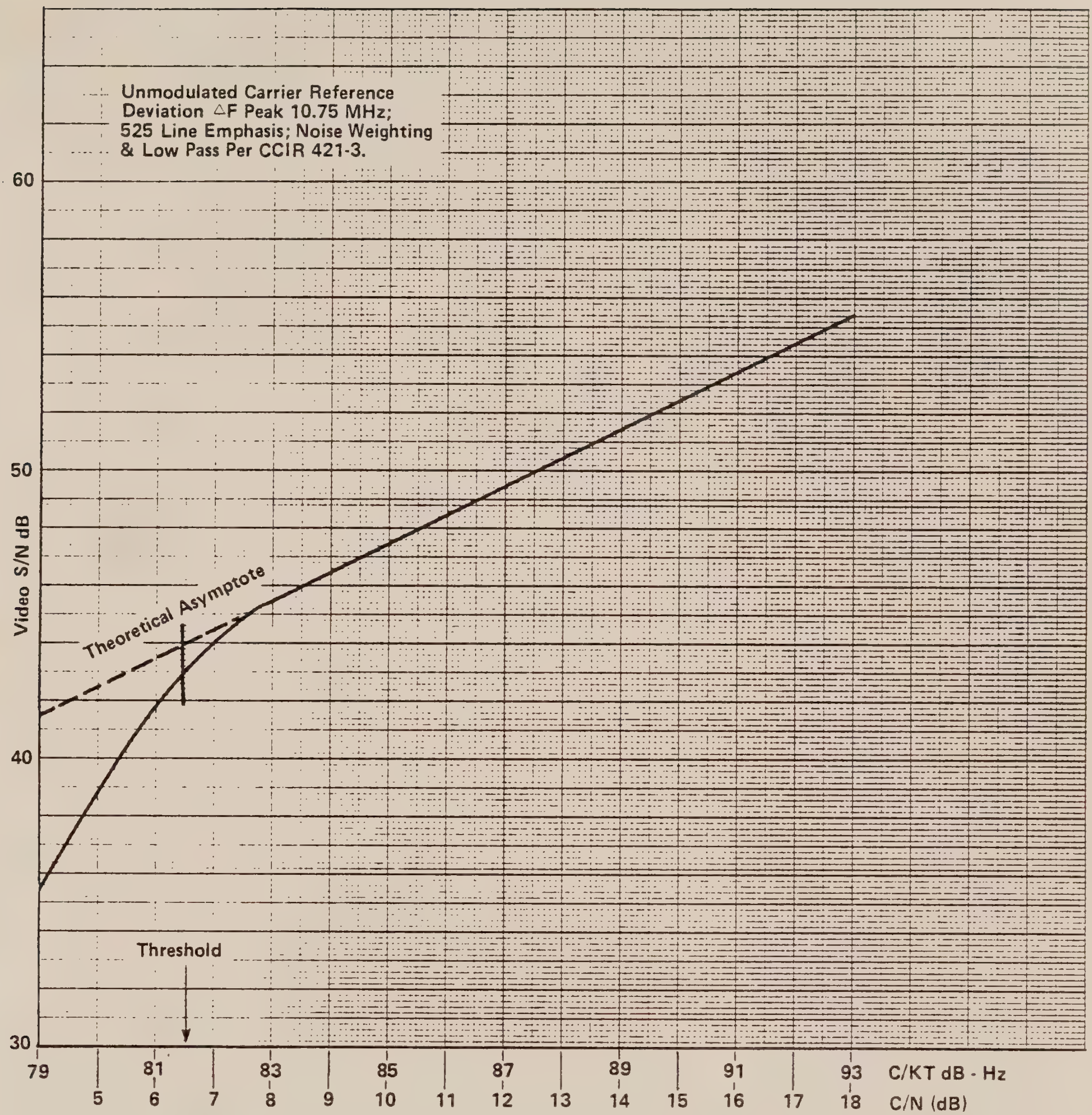



Figure 6. Series 6600 Video Receiver Threshold Performance

**Table 1. PRELIMINARY SPECIFICATIONS**
**Series 6600 Video Receiver**

RF INPUT
- Maximum Level
  - −30 dBm
- Frequency
  - 3700 to 4200 MHz
- Impedance
  - 50 ohms
- Return Loss
  - ⩾20 dB
- Noise Figure
  - 15 dB maximum
- Image Rejection
  - >60 dB
- LO Leakage
  - <−70 dBm

IF
- Intermediate Frequency
  - 70 MHz
- Bandwidth
  - 30 MHz nominal
- Impedances
  - 75 ohms, unbalanced
- Return Loss at IF Monitor Ports
  - ⩾20 dB
- Dynamic Operating Range
  - 40 dB

BASEBAND
- De-Emphasis 525 Line
  - CCIR Rec. 405-1
- Deviation Range
  - 6 to 12 MHz peak at de-emphasis cross-over frequency

VIDEO
- Video Level
  - 1Vp-p ±3 dB adjustable
- Impedance
  - 75 ohms, unbalanced
- Return Loss
  - ⩾20 dB
- Polarity
  - Black-to-white: positive-going
- Clamping
  - 40 dB dispersal rejection
- Line-Time Waveform Distortion
  - <1% tilt
- Field-Time Waveform Distortion
  - <1% tilt
- Differential Phase
  - <±1° 10-90% APL
- Differential Gain
  - <±2.5% 10-90% APL

AUDIO
- Subcarrier Frequency
  - 6.8 MHz standard, other frequencies available
- Frequency Response
  - 50 Hz to 15 kHz ±1 dB
- De-Emphasis
  - 75 microseconds
- Output Level
  - Continuously variable, 0 dBm to +10 dBm
- Impedance
  - 600 ohms balanced
- Harmonic Distortion
  - ⩽1%

CONTROLS

**Rear Panel**
- Power
  - On/Off
- Auto-Local-Remote Switch (Model 6602)
- Selects automatic, local, or remote control method of channel selection

**Front Panel**
- Channel Selector (Model 6601)
  - Selection of channels is accomplished by changing crystals. No tuning is necessary
- Channel Selector (Model 6602)
  - Switch selectable −24 Channels
- Video Gain
  - Adjust video output level to 1 volt ±3 dB
- Audio Gain
  - Adjust audio output level 0 to +10 dBm
- AGC/MGC Switch
  - Select automatic or manual gain control of 70 MHz IF Filter/Amplifier
- MGC
  - Adjust gain of IF Filter/Amplifier
- Zero on Noise
  - Allows meter to be calibrated for C/N measurements

**Operating Temperature**
- 0° to 50°C

**Mechanical**
- 5-1/5″ x 19″ x 19″

**Power Requirements**
- Approx. 50 watts

5.0 Summary Evolution of video receivers has occurred rapidly during the past three years. Volume production is now the goal in this expanding market. Versatility and lower cost to the customer will be the main benefit brought about by this increase in volume.

# DIGITAL SIGNAL PROCESSING FOR SMALL APERTURE EARTH TERMINALS

James S. Gray
Principal Engineer

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Abstract** Large earth terminals can support enough digital carriers such that operation becomes bandwidth limited. This condition requires the use of bandlimited QPSK modems to minimize channel spacing. The long-term trend, however, is toward small aperture ground stations with antenna sizes of 5 meters or less. The number of digital carriers that such earth terminals can support and yet provide adequate BER performance implies channel spacings such that operation becomes strictly power limited and not bandwidth limited. This condition suggests that BPSK modems with gentle filtering are most cost-effective.

## DIGITAL SIGNAL PROCESSING FOR SMALL APERTURE EARTH TERMINALS

### Introduction

The present trend is toward smaller earth terminals. Let us arbitrarily define a Small Aperture Earth Terminal (SAT) as one with an antenna size of 5 meters or less. In the past with much larger antennas, such as 30 meters, operation at lower data rates (less than T2 rates) could be bandwidth limited. Therefore a bandwidth efficient modulation scheme such as Nyquist filtered QPSK should be used. In Table 1 the maximum number of users due to bandwidth restrictions in a 36 MHz transponder that are allowed by several different modulation schemes for an information data rate of 56 Kb/s with FEC coding at an r = 7/8 rate are presented.

With bandlimited QPSK modems and a channel spacing of 1.5 times the baud or symbol rate of the modem, 750 users could be accommodated by the link. If wideband QPSK modems with simple filtering to restrict the bandwidth to the main lobe are used, 562 users could be accommodated. Going to bandlimited BPSK modems and a channel spacing of 1.5 times the bit rate results in 375 users. Finally BPSK modems with main lobe filtering so that channel spacing is twice the bit rate results in 281 users. The complexity and thus cost of the modem monotonically decreases as one goes from left to right in the table.

### Link Considerations for Small Aperture Earth Terminal

Some simple link calculations for the SAT should reveal the influence of power and bandwidth on operation and thus which modulation schemes are most appropriate for SAT networks.

At the SAT we have

1. $C_i/N_o/_{Total} = E_b/N_o + R$

$C_i$ is power per user, R bit rate in dB

Since we are primarily downlink limited we will assume

2. $C_i/N_o/_{Total} = C_i/N_o/_{down}$

Now

3. $C_i/N_o/_{down} = EIRP - BO_o - N - L_s + G/T/_{ES} - K$

$BO_o$ is output backoff of TWT in dB

N is number of users in dB

$L_s$ path loss in dB of downlink

$G/T/_{ES}$ is G/T of earth station

K is Boltzman's constant in dB

Combining 1, 2, and 3 yields

4. $R + N = (EIRP - BO_o) - E_b/N_o - PL_D + G/T/_{ES} - K$

Let us now choose some reasonable numbers for the right side of the equation.

Assume (EIRP - $BO_o$) = 30 dBw

This number includes about 1 dB for power that is lost in intermodulation products. Such a number is reasonable for several satellites.

Assume the largest SAT antenna of 5 meters and a 120°K LNA at 25°C. This results in a

$$G/T/_{ES} = 22.6\ \mathrm{dB}/°\mathrm{K}$$

Assume that an overall probability of error, Pe, equal to $10^{-8}$ is achieved in the SAT at an $E_b/N_o$ of 11 dB. In Figure 1 the theoretical performance curve for PSK with r = 0.875 self orthogonal convolutional coding with threshold decoding is presented. It is seen that Pe = $10^{-8}$ is achieved at $E_b/N_o$ = 9 dB. The modem-codec would typically be within 1 to 1.5 dB from theory in back-to-back performance testing. In an operational situation situation with allowance for losses due to other ground station hardware, a 2 dB implementation loss is assumed which results in the $E_b/N_o$ of 11 dB assumption for a required error of $10^{-8}$.

Inserting these numbers plus the path loss at 4 GHz and Boltzmann's constant in equation 4, yields

$$R + N = 74.7\ \mathrm{dB}$$

For R = 56 kb/s, 10 log R = 47.5 dB

Thus 10 log N = 27.2 dB or N = 527 users. If one takes into account rain margin, pointing errors, $C_i/N_o/_{Uplink}$, equivalent $C_i/N_o/_{intermodulation}$ etc., the previous results will decrease by at least 3 dB or a maximum number of about 260 users can be supported by the link. To illustrate how the 3 dB minimum reduction is derived, let us consider equivalent $C_i/N_o$ due to intermodulation distortion.

We have

$$C_i/N_o/_{IM} = \frac{C/IM}{IM} + BW - N \quad \text{all numbers in dB}$$

Where

$$C = 7.32\,(bo_o)^{-\alpha} \qquad \alpha = 1.5 \text{ to } 2 \text{ in actual values not dB.}$$

For a 4 to 6 dB output backout a reasonable number for C is 18 dB. BW is the bandwidth of the transponder in dB. Sutstituting the derived value of N yields $C_i/N_o/_{IM}$ = 66.34 dB.

Now

$$C_i/N_o/_{Downlink} = E_b/N_o + R = 11 + 47.5 = 58.5\ \mathrm{dB}$$

$$C_i/N_o/_{Total}{}^{-1} = C_i/N_o/_D{}^{-1} + C_i/N_o/_{IM}{}^{-1}$$

or

$$C_i/N_o/_T = 57.84\ \mathrm{dB}.$$

Thus intermodulation causes about a 0.65 dB reduction. Likewise $C_i/N_o/_{Uplink}$ will typically cause a reduction in $C_i/N_o/_{Total}$ of several tenths of a dB. Thus if one assumes a net 1 dB reduction due to intermodulation and uplink and adds 2 dB for rain margin, pointing errors, and other effects one arrives at the 3 dB reduction previously assumed.

The 260 user maximum is reasonable and seems to agree with statements made by the various specialized carriers. The actual numbers for 56 kb/s service with 5 meter ground stations are typically quoted in the 140 to 200 user range. Referring back to Table 1 it is seen that a maximum number of 260 users is compatible with any of the modulation techniques presented in the table. This result has some interesting implications. With much larger earth stations the historical trend has been to use Nyquist QPSK modems. A specialized carrier or an industrial company setting up a SAT digital network, however, should consider using Nyquist BPSK modems or BPSK modems with simple filtering since the maximum number of users is compatible with the spectrum used by these modems. The BPSK modem is less complex and therefore will cost less than a QPSK modem. The BPSK modem should be more robust than the QPSK modem. Typically in back-to-back performance testing the BPSK modem might perform about 1/2 dB better than the QPSK modem. Similarly degradations caused by temperature, aging, etc., should be less for the BPSK modem. For example carrier reference phase offset only causes a cos $\theta$ signal loss for BPSK but causes both desired signal loss and crosstalk from the quadrature channel with QPSK.

## Summary

In summary the purpose of this paper is to show that the optimum choice of digital modulation hardware for the small aperture earth station may be different from that for larger earth stations. For r = 1/2 convolutional coding with soft bit decisions and decoding using the Viterbi algorithm, the number of 56 kb/s users supported by 5 meter SAT's increases to approximately 500 users thereby approaching bandwidth limited operation. However, the complexity and cost associated with such coding both in the modem andthe codec at the present time seem to be incompatible with the economics of the SAT. The point is that with more complex coding and the proper choice of modulation technique one can usually get to bandwidth limited operation. The SAT in order to be pervasive, however, must be inexpensive. For that reason the coding in Table 1 was restricted toa self orthogonal convolutional code with threshold decoding and the modulation scheme was assumed to be bandlimited BPSK or QPSK. Low cost bandlimited BPSK modem/FEC codec's and bandlimited QPSK modem/FEC codec's are available from several vendors including Scientific-Atlanta. The pricing evolution of these modems is very compatible with the cost requirements of small aperture earth stations for digital data service.

| | Bandlimited QPSK Spacing: 0.75 bit rate | Mainlobe QPSK Spacing: 1 bit rate | Bandlimited BPSK Spacing: 1.5 bit rate | Mainlobe BPSK Spacing: 2 bit rate |
|---|---|---|---|---|
| Number of Users in 36 MHz Transponder | 750 | 562 | 375 | 281 |

Table 1. Number of 56 kb/s Users Bandwidth Limited Only r = 7/8 Coding

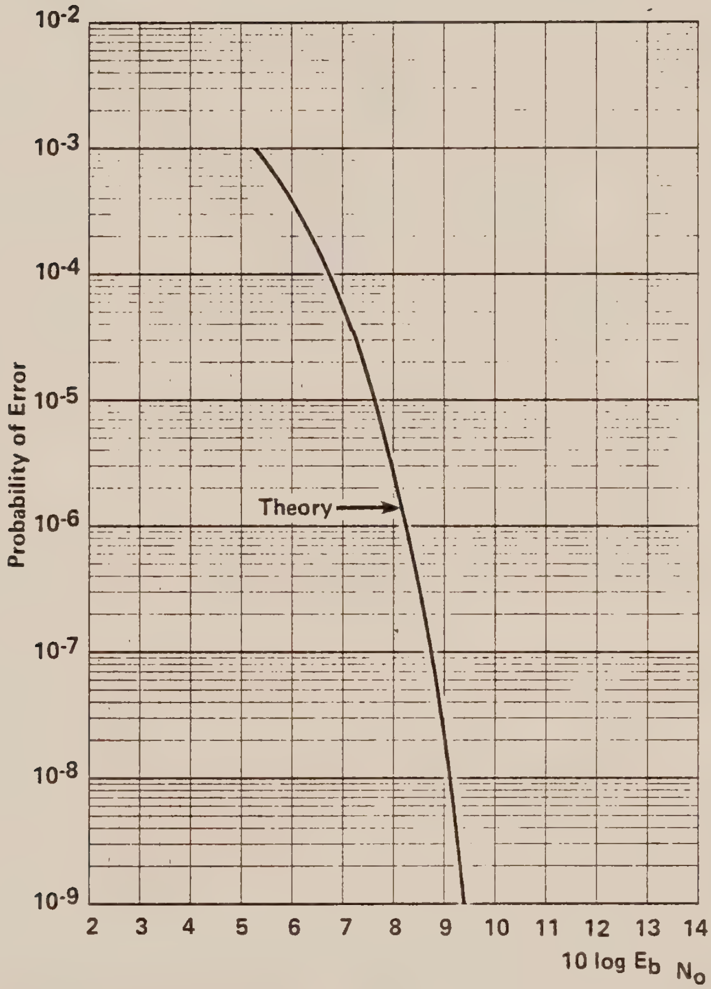



Figure 1. Theoretical Performance for Nyquist BPSK/QPSK Modem + r = 7/8 FEC Codec

# TRANSMITTING EARTH STATION EQUIPMENT

Written by:
Clifford B. Searles
Presented By:
Ray Stuart
Manager Systems Engineering

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Earth Station Transmitting Equipment**

In those terminals having a transmission capability, the equipment that is used to transmit the information signal to the satellite has been lumped together into one group, referred to as the Earth Station Transmitting equipment. Within this group, two very general classes can be defined; one, referred to as the signal processing equipment, and the other as the power amplifier.

The signal processing equipment converts the incoming information stream into a microwave signal, which is then amplified by the power amplifier and beamed to the satellite by the antenna. Very stringent control must be maintained in order to avoid interference with or from other terrestrial communications or microwave systems. Close attention must be given to signal strength, and to modulation levels, to avoid interference with other satellite channels, or with other satellites.

The earth station transmitting equipment must provide a reliable communication link to the satellite, without losing any information content, or causing a degradation in performance of any other systems.

Yesterday, we described in detail the operation of some of the equipment which falls into the general class of signal processors. Flow charts were presented, showing how an information signal (a telephone conversation, a video signal, a data stream, or a combination of these signals) was processed into a suitable modulation impressed upon a microwave signal. The message or video exciter unit provides the microwave signal which is then amplified by the high power amplifier.

The transmitter up-link frequency band covers the range from 5.925 GHz to 6.425 GHz, commonly referred to as the 6 GHz uplink. The 6 GHz uplink band is used by all the INTELSAT IV satellites, and by the current domestic satellite systems.

Future satellite systems will also operate at higher frequencies, with the uplink transmitter band being moved to 14.0 - 14.5 GHz (i.e., the 14 GHz band). The corresponding downlink frequencies will be 11.7 - 12.2 GHz. This capability will be available on the INTELSAT V satellites, and the proposed business satellites offered by Satellite Business Systems, among others. The transmitting equipment requirements will be the same at 14 GHz as at 6 GHz, except for the operating frequency.

**The High Power Amplifier**

The output from the exciter unit will be of the order of −10 dBm (0.1 milwatt). This signal must be amplified a million times or so, to a power level of several hundred watts, to be capable of driving the satellite transponder into saturation.

There are two types of microwave amplifier tube in general use, the klystron and the travelling wave tube. A brief description of the operating characteristics of each will aid in understanding their use, and the advantages and disadvantages of each type.

The travelling wave tube, commonly referred to as a TWT, falls into two classes, helix type TWT's and coupled cavity TWT's. For our discussion we will be chiefly concerned with the helix type TWT's. The helix type TWT is a broad band amplifier with an amplification bandwidth considerably greater than the 500 MHz uplink bandwidth, often covering an octave or more.

Commonly used as a driver amplifier, the helix type TWT is available with saturated output power levels ranging from 100 milliwatts to as much as 600 watts, CW at 6 GHz. To avoid excessive intermodulation distortion which results from the simultaneous amplification of two or more signals at different frequencies, the TWT is normally operated well below the saturation point, i.e., in the linear amplification region, some 6 to 10 dB below the saturation level.

Figure 1A is a typical plot of output r.f. power versus input r.f. drive power. Three operating areas are defined:

> The small signal region, also referred to as the linear operating region. Output power directly reflects variations in input drive power.
>
> The large signal region includes the operating region from where gain compression starts up to the saturation point . ... the point where increases in the r.f. drive level produce no change in the r.f. output level.
>
> Beyond saturation is the overdrive region. Irreparable damage to the tube may result if it is operated with excessive r.f. drive, i.e., in the overdriven condition.

Figure 1B shows the shift in output r.f. phase as a function of the r.f. drive level. The slope of the output phase versus r.f. drive is the AM/PM conversion of the amplifier, i.e., the incremental phase shift of the output r.f. as a result of a change in the amplitude of the input signal. This is shown in Figure 1C.

A typical high gain, high power TWT will have a phase shift of 30 to 50 degrees, with a corresponding AM/PM coefficient of 3 to 5°/dB. The klystron amplifier is electrically shorter than the TWT and will typically have a total phase shift of 15 to 25 degrees, and an AM/PM coefficient of 2 to 4°/dB.

Note that the TWT maximum AM/PM occurs well below saturation, right in the linear operating region.

TWT Transfer Characteristic

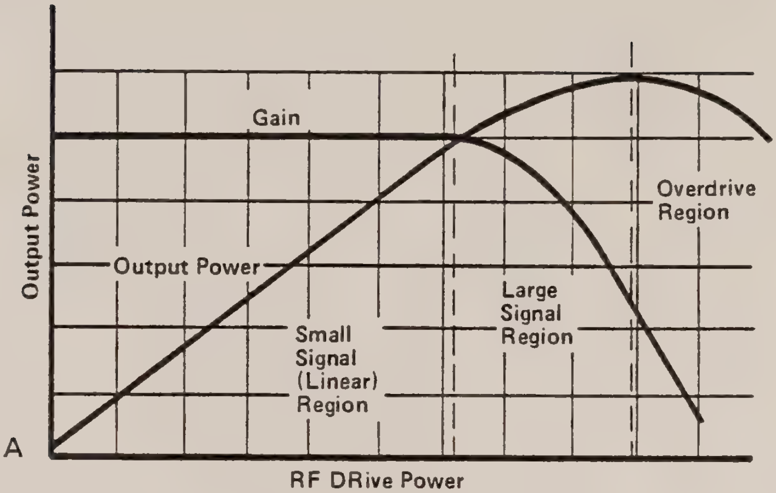



Figure 1A

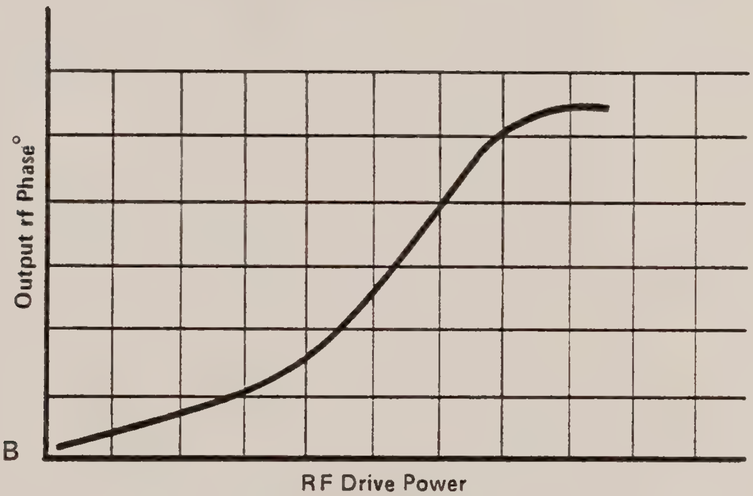



Figure 1B

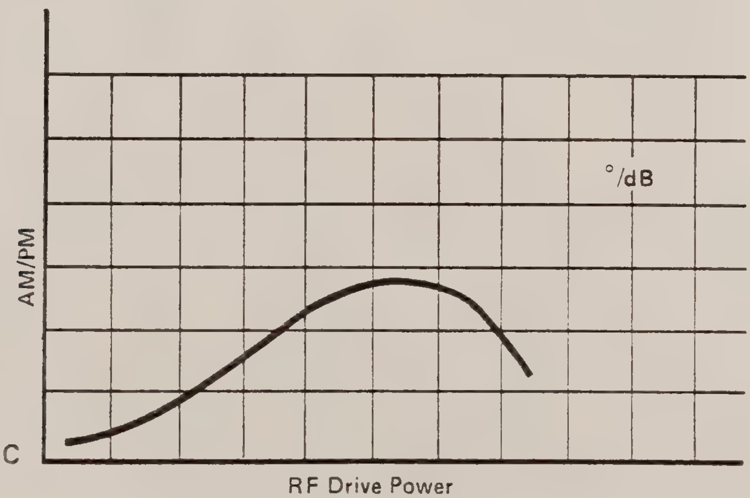



Figure 1C

The frequency response characteristics of the TWT and of the klystron amplifier are shown in Figure 2. The broadband character of the TWT is obvious. The klystron characteristics are dependent upon the tuning of the klystron, and can be varied by adjustment of the individual cavity tuners. The objective is to provide a 36 MHz bandwidth, centered on the appropriate channel frequency, having a minimum variation in gain and output power, without introducing excessive group delay distortion.

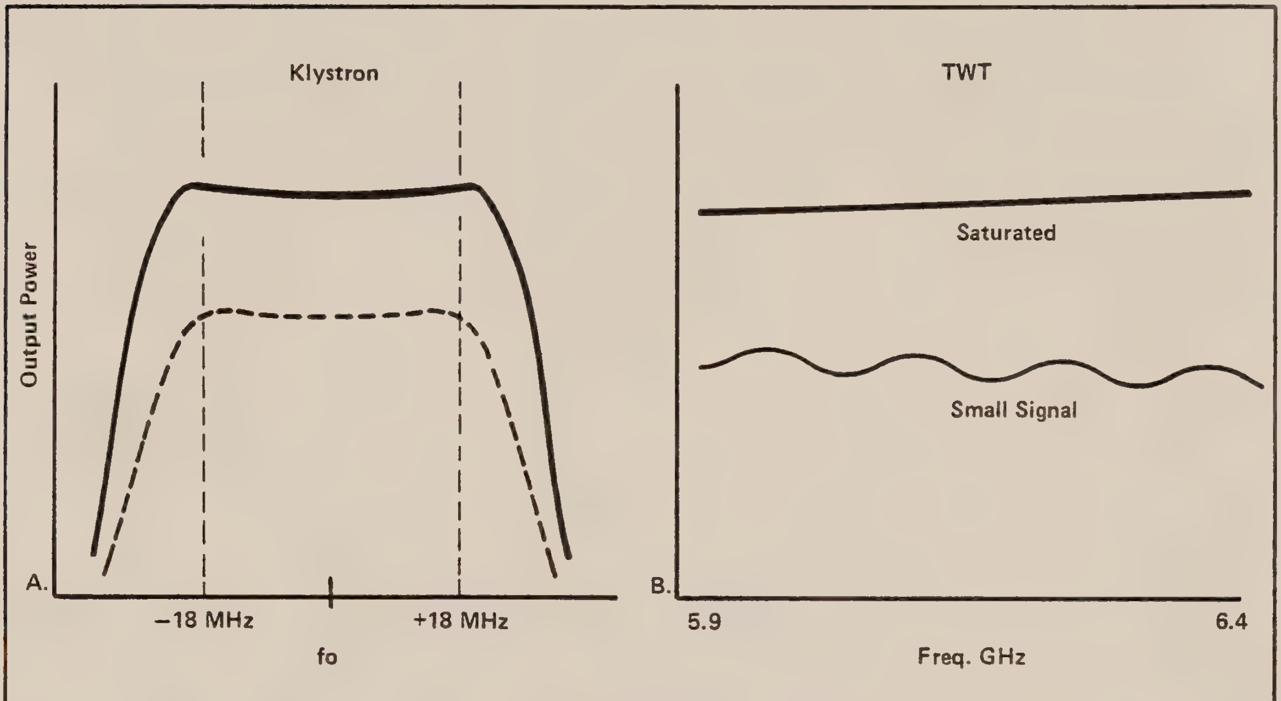



Figure 2. Output Power vs. Frequency.

The normalized group delay for both the klystron and the TWT is shown in Figure 3. An equalizing network in the signal processing equipment provides a means of compensating for the distortions introduced by the klystron amplifier, and by other systems in the loop. It should be noted that equalization is done for the complete transmit-receive loop, rather than for an individual item or component.

Both the klystron and the TWT are classed as non-linear microwave amplifiers, even though they are operated primarily in the linear amplification region, because the output signal will consist of the fundamental carrier frequency as well as harmonics of the carrier frequency/or frequencies. As a result of the broadband characteristic of the TWT, the TWT harmonic content is much greater than for a comparable klystron. As an example, when operating at saturation, the TWT output power at the second harmonic may be within 8 dB of the fundamental power level, whereas the klystron second harmonic level will typically be 25 dB below the fundamental.

A harmonic filter is placed in the output r.f. line to attenuate or reject these harmonics, allowing only those frequencies in the 5.925 - 6.425 GHz band to pass through to the antenna.

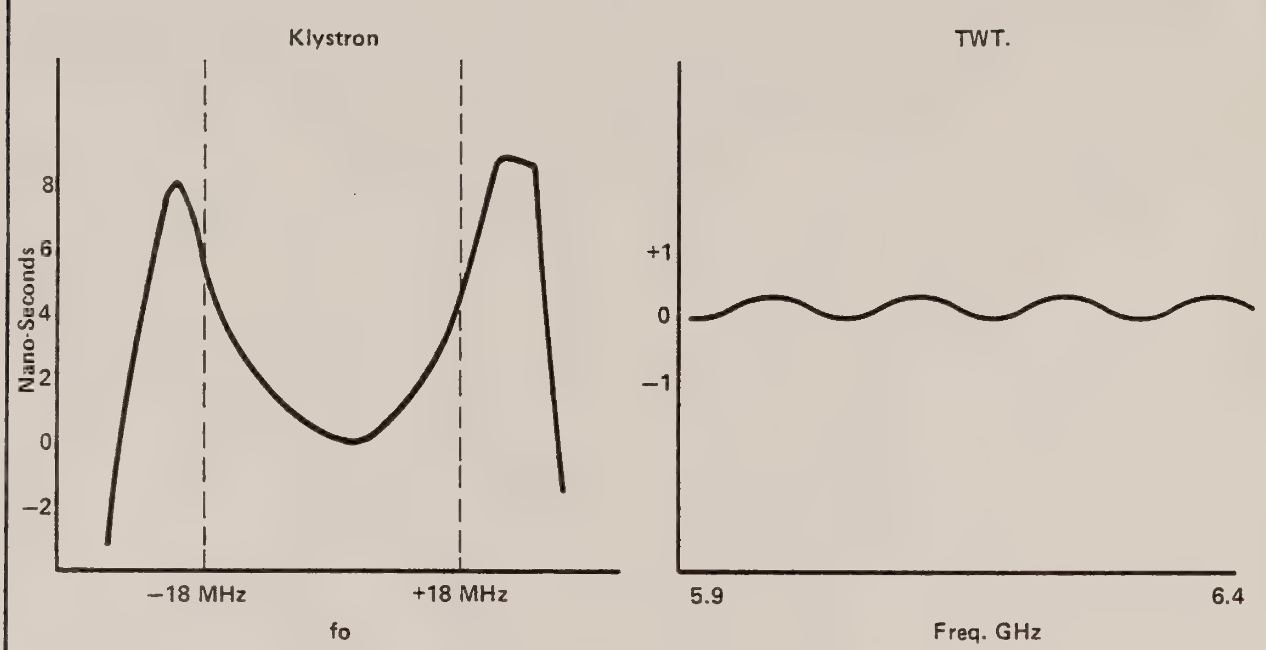



Figure 3. Group Delay.

However, if the transmitted signal consists of more than one carrier, this non-linear characteristic produces intermodulation products which fall within the transmit band, and in most cases will be within the 40 MHz transponder channel.

Let us illustrate what happens, using two signals, separated 5 MHz apart.

Let $f_1$ be 5,960 MHz, and $f_2$ be 5,965 MHz. The generated harmonics, $2_{f_1}$ (11.920 GHz) and $2_{f_2}$ (11,930 GHz) are stopped by the harmonic filter, as are the summed even ordered mixing components, $f_1 + f_2$ (11.925 GHz), $2_{f_1} + 2_{f_2}$ (23.850 GHz), etc. The difference components, $f_2 - f_1$, (5 MHz), and $2_{f_2} - 2_{f_1}$ (10 MHz), etc., cannot propagate in the waveguide. However, the odd ordered components will fall in the operating bandwidth, and will appear as spurious sidebands. The principal component will be the third order intermodulation products from $2f_2 - f_1$, and $2f_1 - f_2$, which produce signals 5 MHz above $f_2$ ($2f_2 - f_1$ = 5970 MHz) and 5 MHz below $f_1$ $2f_1 - f_2$ = 5955 MHz). The 5th order components ($3f_2 - 2f_1$, $3f_1 - 2f_2$, etc.) will be 5 MHz above and below the 3rd order, etc.

Intermodulation distortion is shown in Figure 4, for two equal carriers, at a combined output power level approximately 10 dB below the saturation power level, i.e., at approximately 10 dB backoff.

A typical requirement for an earth terminal transmitter is that the 3rd order distortion sidebands be 26 dB below either of two equal carriers. These sidebands levels increase as the klystron or TWT is driven toward saturation.

Distortion is less in a klystron than in a TWT, as is shown in Figure 5, where the 3rd order sideband to carrier level has been plotted versus backoff from saturation. Note that the klystron has approximately 5 dB less distortion than the TWT, at any given backoff operating point.

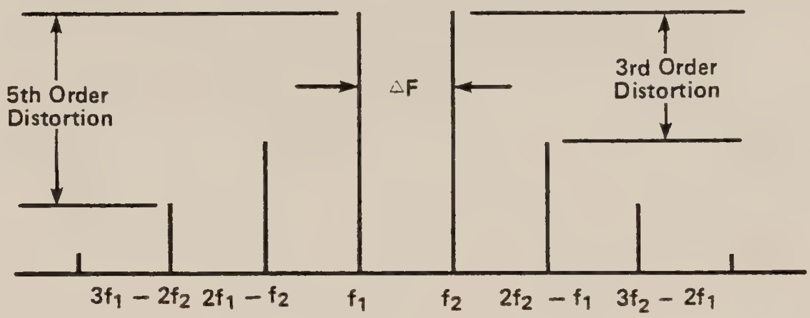



Figure 4. Intermodulation Sidebands.

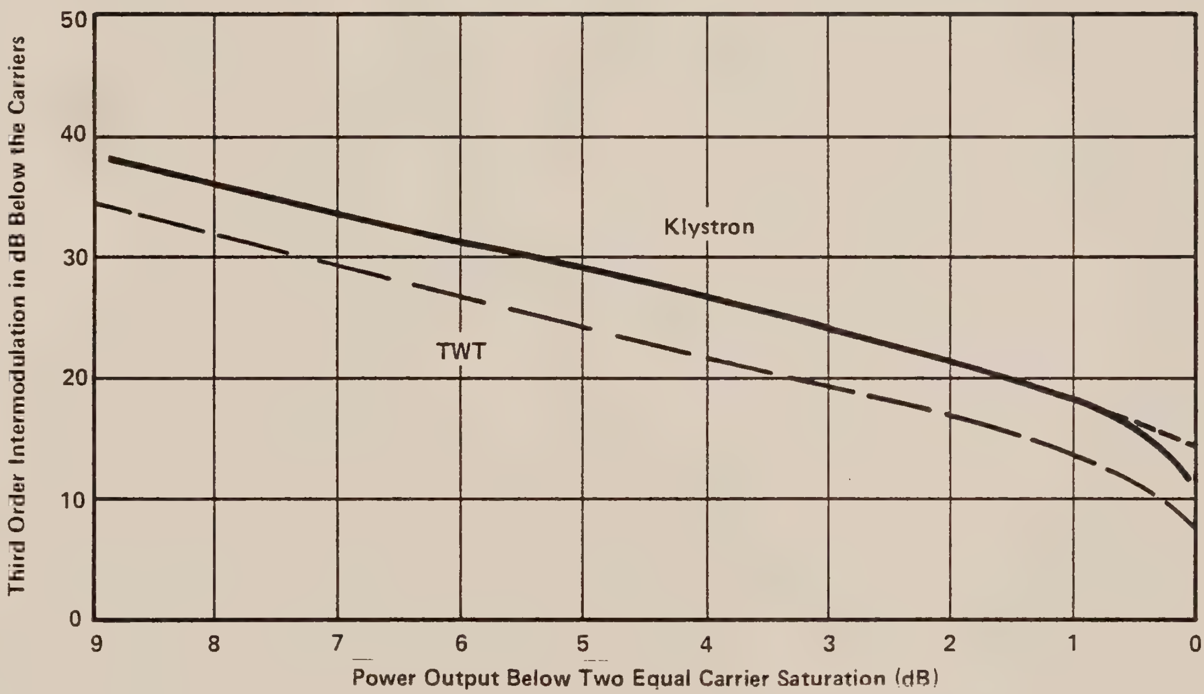



Figure 5. Third Order Intermodulation Distortion Under Two Equal Carrier Conditions.

The helix TWT is in general use as an intermediate power amplifier (IPA) operating in the 2 to 10 watt range, as the driver for a high power klystron. The high power TWT, in the 400 to 600 watt range, is used as the final output amplifier in small terminals of limited channel capacity for thin-route telephone service, or in dedicated data transmission service.

A block diagram of a typical 3 Kw HPA, complete with driver IPA and output harmonic filter, is shown in Figure 6. This is representative of the HPA used by Scientific-Atlanta for video earth terminals.

This amplifier provides a total gain of 80 dB, with bandwidths up to 45 MHz for each channel. The power output is set by the klystron, with 1.5 Kw and 3 Kw types in general use. Two tuning options are available for the klystron, either a 6 channel tuner or a 12 channel tuner. Changing channels requires less than 5 minutes. A motor driven automatic channel selector is also available.

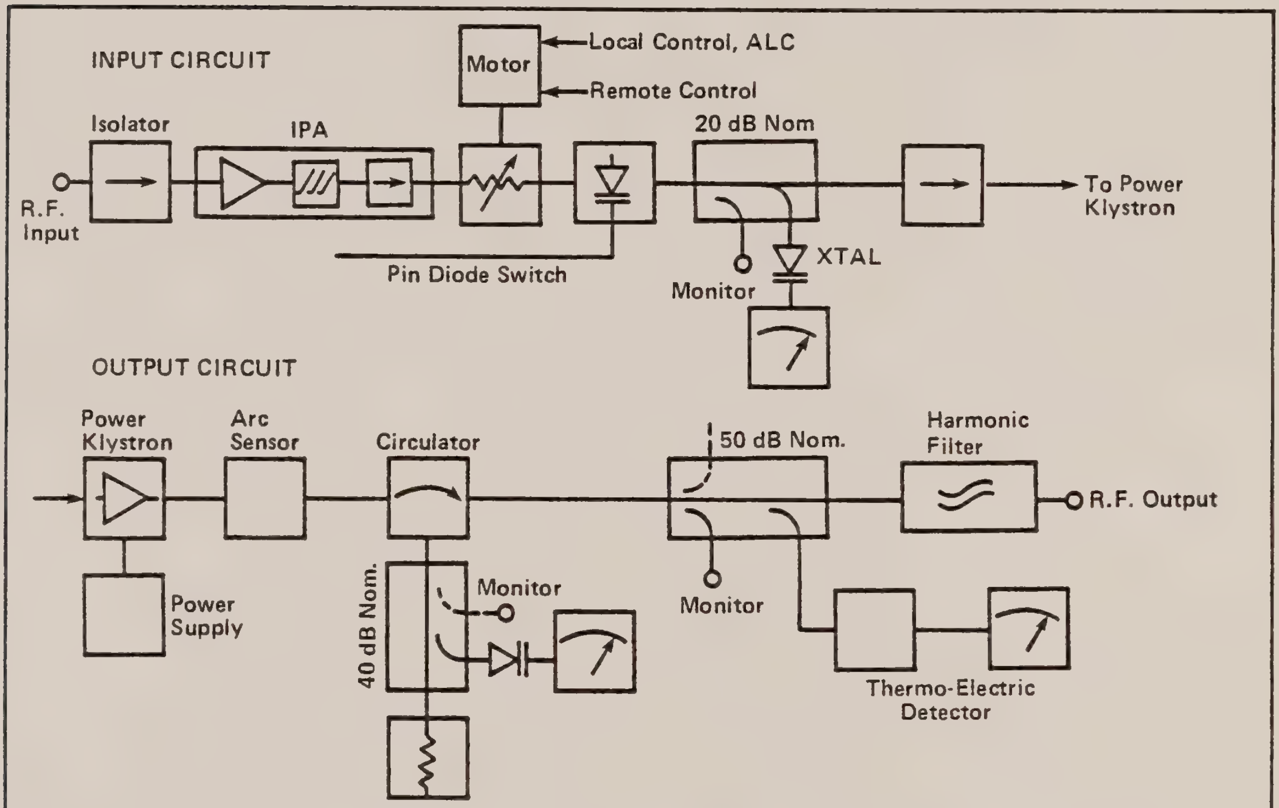



Figure 6. Typical 3 kW HPA R.F. Circuit.

The complete HPA is mounted in a 78 inch cabinet as shown in Figure 7. This unit weighs approximately 1500 lbs., with about 800 lbs. being in the klystron high voltage power supply located in the bottom of the cabinet. This power supply is mounted on wheels, and can be easily rolled out of the cabinet for inspection or repair.

12 to 13 Kw of 208V 3$\phi$ 4 wire primary power is required. Self contained air cooling is provided for the klystron and all accessory equipment, with air drawn in the lower back panel and exhausted out the upper back panel. Normally, the HPA cooling system is vented to the outside air, so that the heat load presented to the station air conditioning equipment is only about 1 Kw.

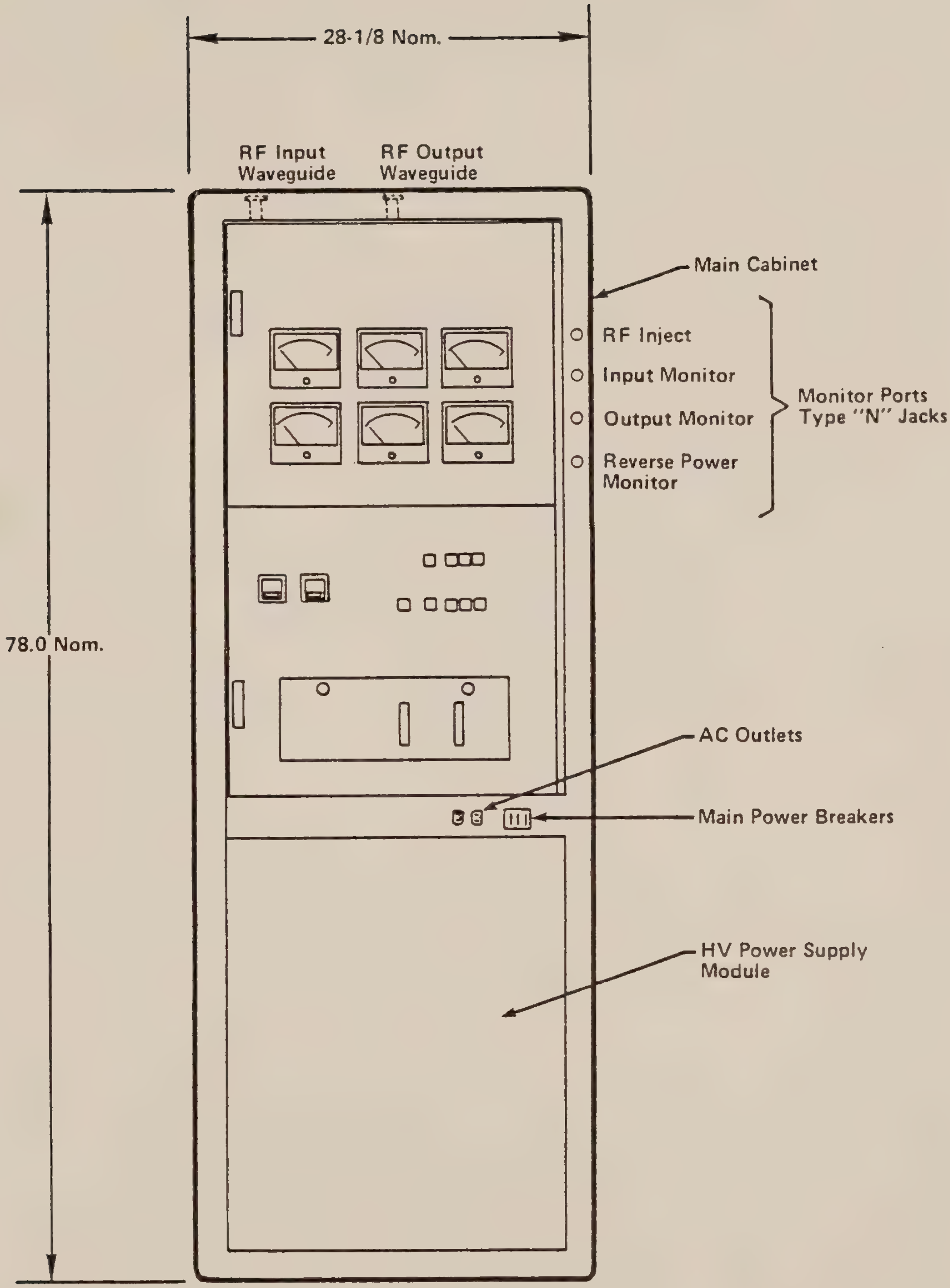



Figure 7. Typical 3 kW HPA

**R.F. PERFORMANCE**

**Frequency Range**
5.925 - 6.425 GHz

**Tuning**
6 or 12 pre-tuned 45 MHz channels available

**R.F. Power Output** (Option)
1.5 Kw
3.0 Kw

**Instantaneous 1 dB Bandwidth**
Up to 45 MHz per channel

**HPA Gain**
80 dB with IPA

**Gain Slope & Ripple**
0.02 dB/MHz to total of 0.5 dB over center third of bandwidth

0.04 dB/MHz to total of 1.0 dB over remaining two thirds of bandwidth

**Gain Stability**
±0.25 dB/24 hours

**Load VSWR**
1.5:1 for full specification performance

**Infinite VSWR**
No damage

**AM/PM Conversion**
Less than 4°/dB at rated output

**Group Delay**
- Linear
  - 0.85 nsec/MHz
- Parabolic
  - 0.05 nsec/$MHz^2$
- Ripple
  - 2 nsec, p-p

**Harmonic Output**
−35 dBc, w/o filter
−80 dBc, with filter

**Input Variable Attenuator**
20 dB minimum range

**Residual F.M.**
Less than 4 kHz p-p

**Spurious Outputs**
a. −50 dBw in any 4 kHz band in 5.9 - 6.4 range
b. −130 dBw in any 4 kHz band in 3.7-4.2 range
c. −110 dBw in any 1 MHz band in 3.7-20 except Tx band
d. −50 dBw in any 4 kHz band in 13.8-14.5 range
e. −100 dBw in any 4 kHz band in 10.8-13.8 range
f. −110 dBw in any 1 MHz band in 14.5-40 range

Residual A.M.
See Figure 8

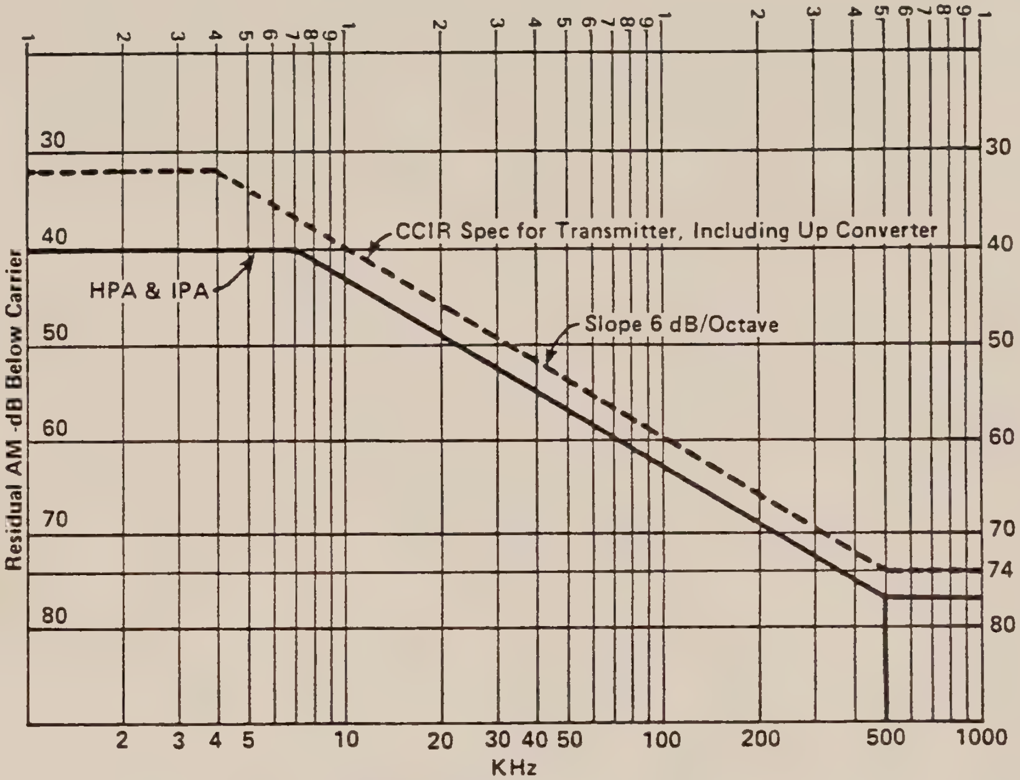



Figure 8. Residual AM.

**ENVIRONMENTAL LIMITS**

**Ambient Temperature**
- Operating
  - 10°C to +55°C
- Storage
  - –40°C to +70°C

**Humidity**
- To 100%
- No condensation

**Altitude**
- Operating
  - 3000 metres (10,000 feet)
- Storage
  - 15,000 metres (50,000 feet)

**Salt Atmosphere**
- As in coastal regions

**Fungus**
- Treated for fungus resistance

**Vibration**
- Transport
  - As encountered in normal shipping and handling
- Operation
  - As encountered in Earth Station

**OPERATING CHARACTERISTICS**

**HPA Turn-On Time - Filament Delay**
5 min. max. from cold start, proportional thereafter.

**Prime Power Interrupt - Automatic Recycle**
HPA recycles automatically with Proportional Filament time delay. For Prime Power Interrupt less than 10 seconds, filament delay does not occur. The HPA snaps on to full voltage upon restoration of prime power.

For Prime Power interrupts of 10 seconds to 5 minutes, filament time delay is roughly proportional to off time, up to a maximum of 5 minutes.

Tolerance on Time Delay: ±20%

**Automatic Fault Recycle**
After a fault signal, the HPA makes three recycle attempts each of nominally 5 seconds duration. If one of these attempts is successful and no fault occurs within 30 seconds after restoration of full performance, the fault counter is reset to zero events. If all three attempts are unsuccessful, the amplifier shuts down until manually reset. This lockout condition is registered on a front panel lamp. The types of fault which have occurred since the last fault indicator reset are stored on their individual fault indicators.

Thermal overload of the klystron collector causes permanent amplifier lock-out.

Prime Power interrupts will not induce RF lock-out. A primary power interruption of greater than approximately 0.1 second causes fault reset. In the manual mode, all recycle circuitry is bypassed.

**Cooling System**
Push Fan, high volume, low velocity low audio noise. Front access filter removal with no HPA shutdown.

**Audio Noise**
Less than 70 dBa

**Back Pressure of External Ducting**
0.1" water max.

**Meters, Controls, and Indicators**

Metering

- RF Output: High-Low trip alarm
  Range switch with 10 dB scale adjust
  Calibrated in watts and dBw
- RF Reflected (Hi-trip)
- RF Drive, 1.5 watt FSD, calibrated in watts and dBm
- Filament & Beam hours
- Collector current-high trip
- Body Current - high trip
- Beam volts
- Filament volts
- Filament current
- AC phase

**H.P.A. FEATURES**

Beam voltage (Variac) Front Access Adjustment
Attenuation Adjustment, Manual
- Optional Motor Driven

Prime Power On-Off Circuit Breaker

Circuit Breakers:
- Main Line — $3\phi$
- Blower — $3\phi$
- Low Voltage Supply — $1\phi$
- Variac Motor — $1\phi$
- Filament Supply — $1\phi$
- Bias Supply — $1\phi$
- Crowbar — $1\phi$
- Contactor — $1\phi$

Switch/Indicators:
- Standby (request) (Filament On, Beam Off)
- Transmit (request) (Beam On)
- Fault Reset
- Meter Range Switch
- W/G Arc
- Auto Recycle
- Remote/Local Control
- ALC On-Off

Status Indicators
- Beam Delay
- Beam Ready
- Drive Lockout
- Recycle Delay
- Recycle Drive Lockout

Fault Indicators:
- Beam O.L.
- Body O.L.
- External Interlock Open
- Internal Interlock Open
- R.F. Low
- R.F. High
- R.F. Reflected — High
- Air Flow Low
- Collector Temp — High
- Filament P.S. Fail
- W/G Arc

HPA Options — Summary:
- Automatic Level Control (ALC)
- Remote Control Module
- R.F. Monitor Ports for IPA, & Reflect Power
- Optional Metering
- Thermal Monitors on IPA, & Reflected Power
- IPA — Integrated
- Fast RF Fail Detect
- Motor — Driven IPA Attenuator
- Optional Indicators & Controls
- Single Phase, or Other Line Voltages
- Regulation Over ±15% Line Voltage
- Transportable and Mobile HPA
- RF Injection Coupler
- Pressure Bleed or Pressure Window

**Remote Control**

Metering
- RF Output
- Range Switch with 10 dB Scale Adjust

Controls
- RF Input Attenuation

Switch/Indicators
- Standby
- Transmit
- Fault Reset
- Range Switch

Status Indicators
- Beam Delay
- Beam Ready
- RF Drive Lockout

Fault Indicators
- Beam Overload
- Body Overload
- External Interlock Open
- Internal Interlock Open
- RF Output High
- RF Reflected High
- Air Flow Low
- Collector Temp High
- Filament Fail
- W/G Arc

**Protection Switching**

Protection switching for the transmitter portion of the communications link has the same purpose as the downlink protection circuitry described in an earlier paper. The major objective is to maintain an active operating system, even though one or more of the components in that link have failed.

The simplest, and most common protection system is a 1 for 1 redundant system, where a back-up, or spare unit is provided for each of the major elements in that system. A failure of the on-line element initiates an alarm, or in the case of an automatic switchover system, starts a sequence of events to switch the standby unit on-line and provide an indication that the primary system has had a failure.

Each piece of equipment in the earth station has its own failure sensing circuits, and will provide an alarm output in the event of a malfunction. This alarm triggers a logic circuit and/or alerts the station operator, for appropriate corrective action.

The signal processing equipment for our purposes is lumped into one general class and labeled the RF exciter unit. Figure 9 is a typical 1:1 exciter protection switching network.

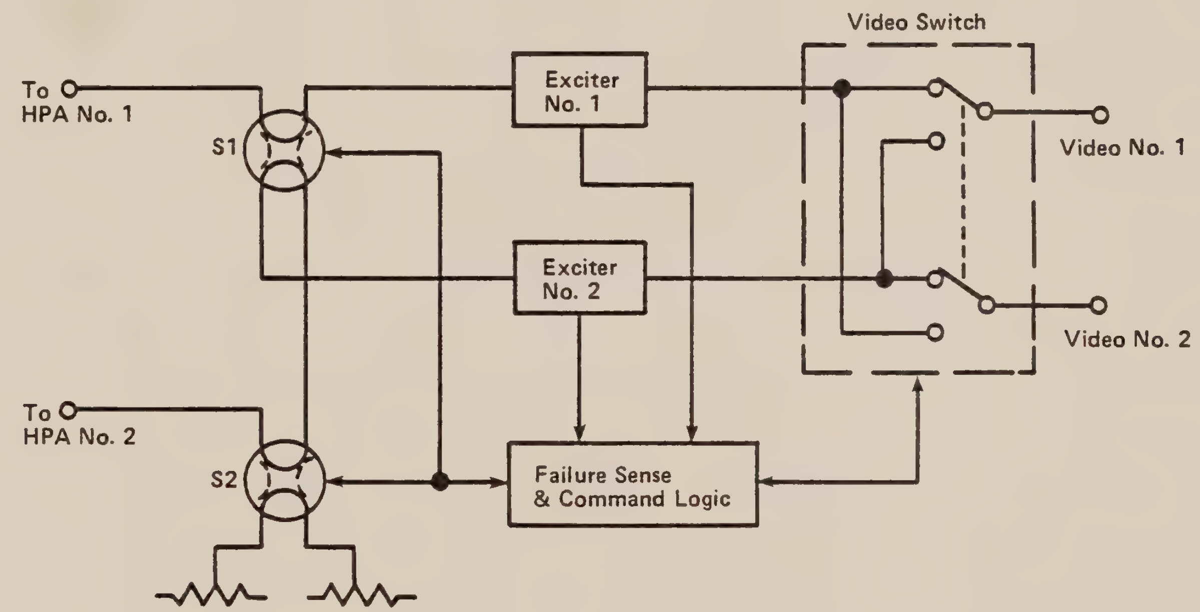



Figure 9. Typical 1:1 Exciter Switching.

Two uplink channels may be operated simultaneously with the switches in the positions shown. In this case, there is no backup protection, and a failure takes that channel off the air. The priority channel can be maintained by appropriately routing the priority signal. For example, a failure of exciter No. 1, with Video No. 1 priority, requires a change of both video switch and S1, to route the Video 1 signal through Exciter 2, and through S1 to HPA1. Exciter 2 must also be re-programmed to the proper uplink frequency. Switch S2 provides a means of terminating the exciter output (and the input to HPA No. 2), and is often not included.

The exciter unit has a plug-in alarm module which serves as a fault indicator and summary fault alarm. The exciter alarm module will register a fault upon the loss of any of the following monitor inputs:

- Various Supply Voltages
- 1st LO Phase Lock
- 2nd LO Phase Lock
- Output Level
- Deviation

In addition, the video EDU plug-in has an alarm which is triggered by loss of dispersal synchronization, while the message pilot/noise monitor plug-in has an alarm which activates on excessive noise or loss of pilot level.

A typical 1:1 HPA switching network is shown in Figure 10, configured for combined operation of both HPA's. The output of each HPA goes to a waveguide switch (S2 and S3) each of which is capable of handling the combined RF output power of both HPA's. The HPA's are operating at different frequencies, with the RF outputs combined through a hybrid Tee. The power from each HPA divides in the Tee, with half going to the antenna and half to the high power load L1. Note: Both L1 and L2 must be capable of dissipating at least 3 kW without overheating, if 3 kW HPA's are used.

This configuration provides no back-up protection, but does provide the flexibility of using the back-up unit for occasional transmission capability, without interfering with the operation of the primary channel.

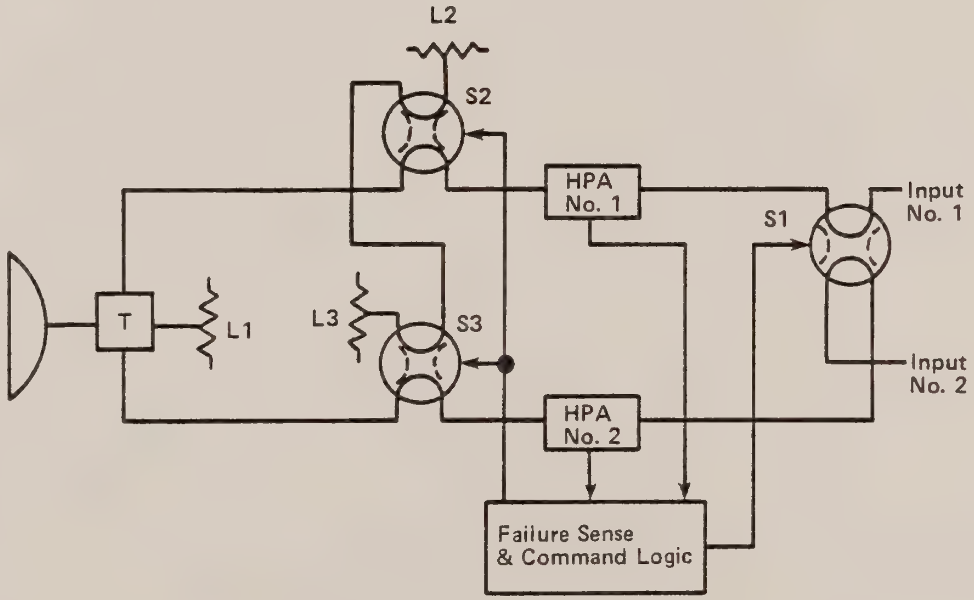



Figure 10. Typical 1:1 HPA Switching Network Configured for Combined Output.

Figure 11 shows the configuration for normal back-up operation. S3 is in position 2, with the output of HPA–2 coupled through S2 to high power load L2, providing for off-the-air checkout and operation. Note: Only two high power loads are required, L1 and L2. L3 is a low power load (typically 75 to 100 watts) as it terminates the hybrid Tee sidearm where the maximum power level is quite low.

A failure of HPA–1 activates the logic circuit, which activates S2, switching HPA–2 on-line, and HPA–1 to dummy load L2. Simultaneously, S1, a co-axial transfer switch, is energized, transferring input 1 (from exciter No. 1), to HPA–2.

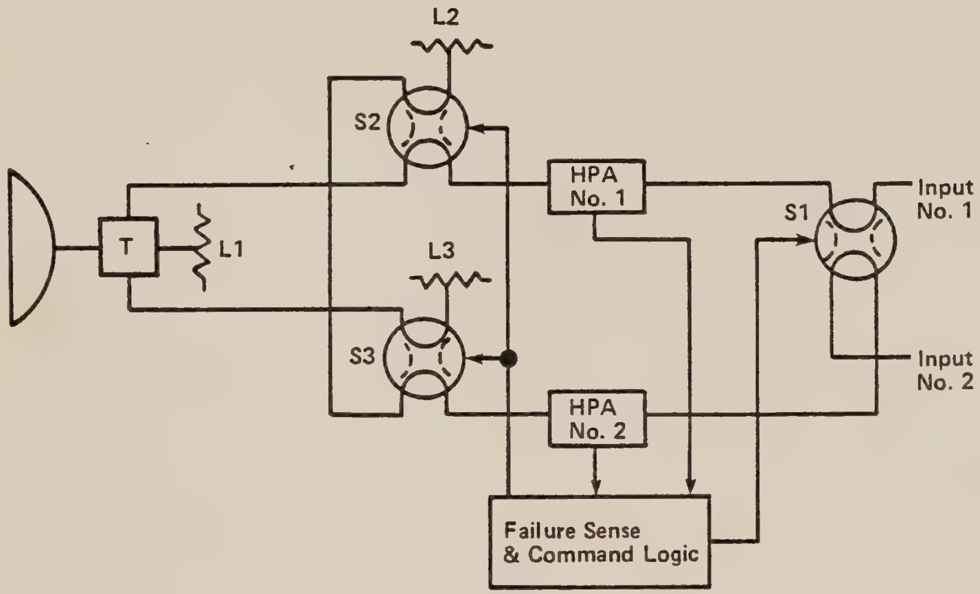



**Figure 11. HPA Switching Network, Normal/Backup Configuration.**

For completely automatic operation, HPA No. 2 must be provided with motorized frequency control so that the operating frequency can be changed to the correct transponder.

When under manual control, particular care must be taken to insure that each HPA and exciter are tuned to the correct frequency.

The individual HPA's are protected by their own internal protection circuitry, with automatic shutdown provided on most units. A summary fault alarm provides the indication to the logic control circuit that a malfunction exists.

The following operating conditions are normally monitored:

| | |
|---|---|
| Low RF Output Power | Loss of Airflow |
| Excessive (High) RF Output Power | High Collector Temperature |
| High Beam Current | Loss of Filament Power |
| High Body Current | Waveguide Arc |
| High Reflected Power | Open Interlock |

The control system required for a completely redundant large earth station can become quite complicated, particularly if you visualize the complexity involved in providing 1:n protection for n's greater than 2.

# DOWNLINK VIDEO PROTECTION

Fred Warren
and
Barry Sharp

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Introduction** The purpose of this presentation is to discuss video protection and its effect on the reliability of a video receive system. Reliability analyses in terms of availability and downtime are performed in detail for a system operating without redundancy, for a system with a 1:1 protection switch, and for a system with a 1:N protection. Some possibilities in protection switching are described for 1:1 protection switch and 1:N protection switch. Two Scientific-Atlanta protection switches are described in Appendix A and Appendix B.

**Definition of Terms** In order to perform the reliability analysis, the failure rates of components are first generated. The primary sources for these failure rates are MIL-HDBK-217B and other industry standards. Electrical stress is assumed to be less than 30 percent for both passive and active components. Worst case temperatures were used in the analysis for a fixed ground environment of +40° C. The components used in the analysis are modified commercial grade and are an equal mixture of both military screened and Class C screened components. All components are assumed to have been subjected to a 24-hour burn-in.

Table 1 summarizes the major failure rates used in performing the baseline MTBF analysis of the receiver.

The criterion for a failure is considered to be the inability to receive video or audio communication.

The availability and down time analysis is derived from the failure rates ($\lambda$) listed in Table 1. The mean time between failures (MTBF or $\theta$) is the reciprocal of the failure rates or:

$$\theta = \frac{1}{\lambda}$$

Unit Designation ______________
P/N ______________

| Item Type | Failure Rate Per $10^6$ Hours (MIL HDBK 217B) |
|---|---|
| I.C.'s (TYP MSI) | 0.224 |
| Transistors | |
| Bi-Polar | |
| NPN | 0.150 |
| PNP | 0.230 |
| FET | 0.230 |
| Diodes | |
| Silicon | |
| $\leqslant$500 ma | 0.119 |
| $\geqslant$500 ma | 0.267 |
| Zener | |
| LO PWR | 0.039 |
| HI PWR | 0.0585 |
| LO PWR (TC) | 0.0585 |
| HI PWR (TC) | 0.0878 |
| Resistors | |
| Composition | 0.000018 |
| Metal Film | 0.0024 |
| Comp. (VAR.) | 0.555 |
| Wire Wound (VAR.) | 0.018 |
| Inductors, R.F. | 0.030 |
| Capacitors | |
| Dipped Mica | 0.0002 |
| Ceramic | 0.012 |
| Tantalum (50%V) | 0.0088 |
| Variable | 0.059 |
| Switches | |
| Push Button | 0.660 |
| Rot. Wafer (10 POS.) | 0.552 |
| Relay (SPST) | 0.012 |
| Crystal (Quartz) | 0.020 |
| Other | |
| MTBF = ______________ | Total ______________ |

Table 1. Assembly Failure Rates.

Availability is defined as the capability of a system to successfully perform an intended task.

The operational availability (A) is derived from the relation:

$$A = \frac{\theta}{(\theta + MTTR)}$$

where MTTR is the mean time to diagnose and repair or replace a failed unit.

The availability of a system with an automatic switching redundant receiver is determined in two availabilities, that of the redundant and the non-redundant equipment. The two availabilities are combined by their product to determine the operational availability or:

$$A_{TOT} = (A_R)\ (A_{NR})$$

where $A_{TOT}$ = Total system maintenance operational availability

$A_R$ = Availibility of redundant equipment alone

$A_{NR}$ = Availability of non-redundant equipment alone

The redundant equipment MTTR is simply the automatic sensing and switching time to a redundant receiver. Since this sensing and switching time is but a fraction of a second, the redundant availabilities become virtually transparent and the single point failure (non-redundant) equipment determines availability of the system.

The maintenance downtime (Dt) resulting from the failure of the primary receiver is expressed:

$$Dt = (1 - A_{TOT})\ \text{(operating hours/year)}$$

**Non-Redundant Video Receive System**

Consider a non-redundant video receive system block diagram as shown in Figure 1.

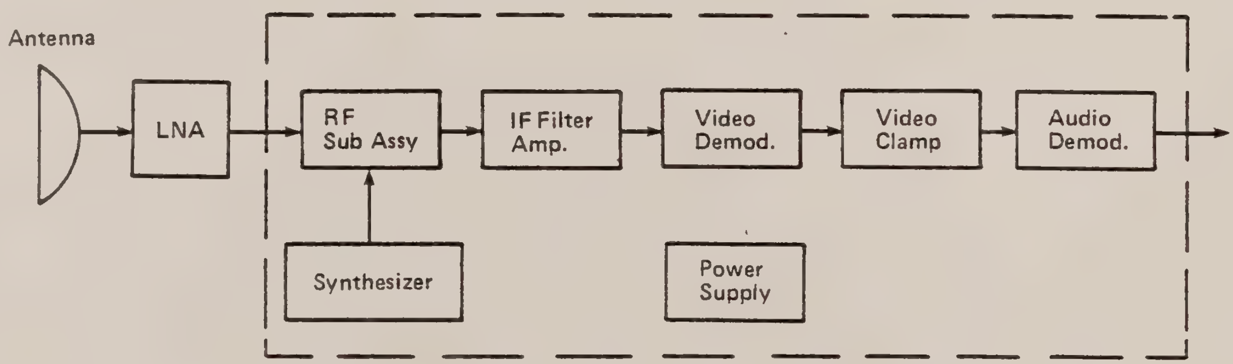



Figure 1. Block Diagram

The failure rate for each assembly in the receiver can be determined by the use of Table 1. The number of each component is multiplied by the Failure Rate per $10^6$ hours. This product multiplied by $10^{-6}$ is the number of failures per hour due to this type component. The total of these products gives the failure rate for the assembly. The failure rate of the receiver is the total of the failure rates of the assemblies.

Failure rates for GaAs FET LNA's (low noise amplifiers) is $10 \times 10^{-6}$ to $20 \times 10^{-6}$ per hour depending on the manufacturer.

Failure rates for Scientific-Atlanta's Model 414 Video Receiver have been compiled in this manner. Figure 2 shows the 414 Video Receiver block diagram with corresponding failure rates.

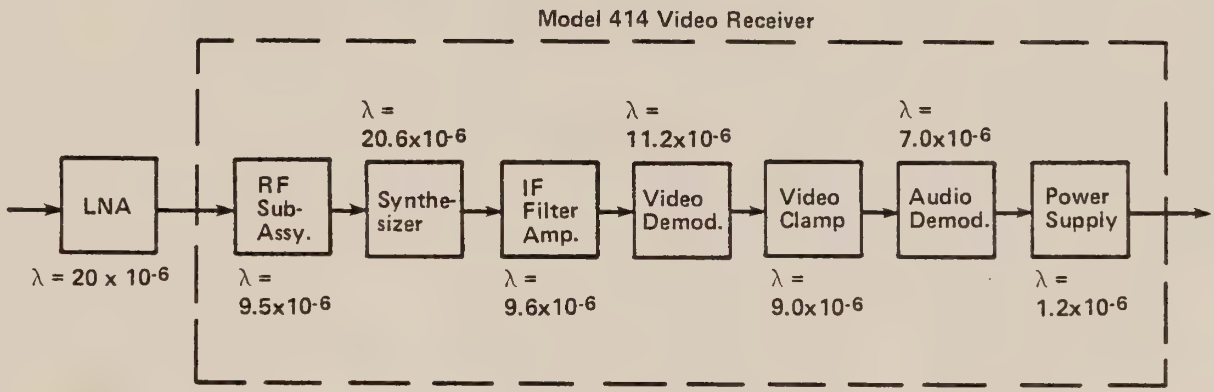



**Figure 2. Availability Model Video Receive System.**

From Figure 2, the failure rate ($\lambda$ Rx + LNA) is computed.

$$\lambda \text{ Rx} + \text{LNA} = \lambda \text{ LNA} + \lambda \text{ Rx}$$

$$\lambda \text{ Rx} + \text{LNA} = (20.0)\ (10^{-6}) + (9.5 + 20.6 + 9.6 + 11.2 + 9.0 + 7.0 + 1.2)\ (10^{-6})$$

$$\lambda \text{ Rx} + \text{LNA} = [(20.0) + (68.1)]\ (10^{-6})$$

$$\lambda \text{ Rx} + \text{LNA} = 88.1\ (10^{-6})$$

The MTBF ($\theta$) for the video receive system is:

$$\theta = 1/\lambda \text{ Rx} + \text{LNA} = 1/(88.1 \times 10^{-6})$$

$$\theta = 11{,}350 \text{ hours}$$

The video receive system availability (A) is now determined by the relation:

$$A = \theta/(\theta + \text{MTTR})$$

It is obvious that the MTTR term is most influential in the availability analysis. For a continuously monitored system, where the technician has immediate access to the equipment, the MTTR is taken as one hour. The availability becomes:

$$A = 11{,}350/(11{,}350 + 1)$$

$$A = 0.99991$$

Based on 24 hours a day operation, the yearly unscheduled down time (Dt) becomes:

$$Dt = (1 - A)\ 8760 \text{ Hours/Year}$$

$$Dt = (1 - 0.99991)\ 8760 \text{ Hours/Year}$$

$$Dt = 0.77 \text{ Hours/Year}$$

Now assume that the site is unmanned with a remote monitor and that it takes 24 hours for a technician to travel to the failed equipment and effect repairs. The MTTR becomes 24 hours. The availability is reduced by:

$$A = 11{,}350/(11{,}350 + 24)$$

$$A = 0.9979$$

The down time then increases to:

$$Dt = (1 - 0.9979)\ 8760\ \text{Hours/Year}$$

$$Dt = 18.4\ \text{Hours/Years}$$

**1:1 Video Protection Switch's Availability Analysis**

Redundant receivers can be provided with 1:1 video protection switch. The block diagram of the receivers is shown in Figure 3.

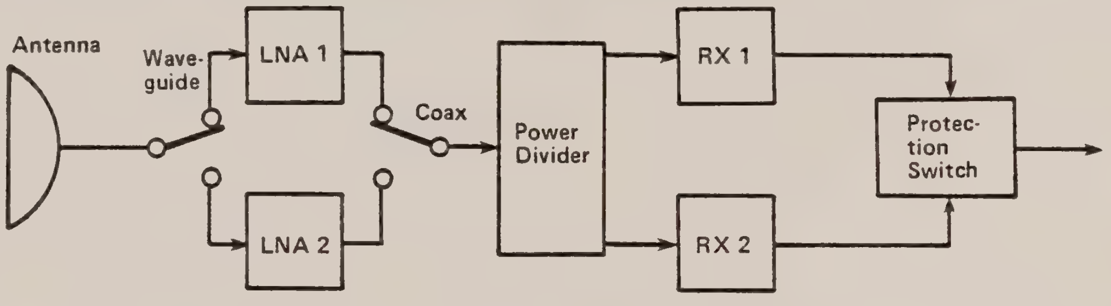



Figure 3. Redundant Receivers (1:1 Protection)

Assume RX 1 and RX 2 are Model 414 Video Receivers. The failure rates of the power divider, waveguide switch, and coax switch vary with manufacturer. The values used in this analysis are typical. The protection switch is divided into three blocks. The alarm blocks are redundant, and the protection switch block is non-redundant. The failure rates of these blocks are calculated in the same manner as the receiver. The failure rates are calculated for Scientific-Atlanta's 1:1 Video Protection Switch. The availability model reduces to that shown in Figure 4.

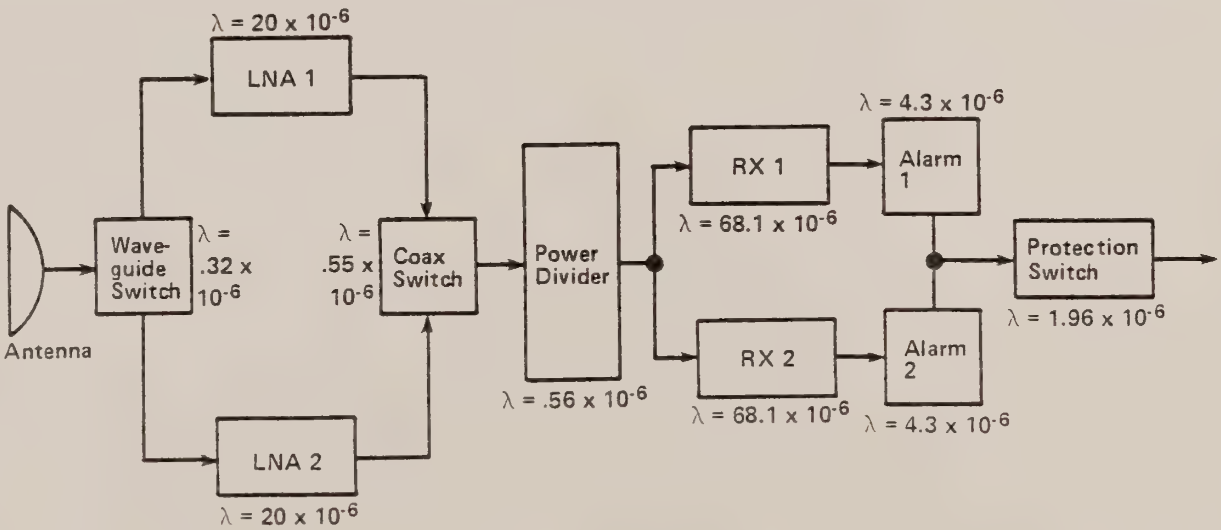



Figure 4. Availability Model for Two Redundant Receivers

Those portions of the protection switch which are common only to the receivers they control are inserted serially with the receivers.

The total availability calculations of this model can be broken down into the redundant and non-redundant equipment failure rates. The individual availabilities can then be determined, and the product taken to achieve the total equipment availability.

First the redundant equipment failure rate ($\lambda R$) is calculated:

$$\lambda R = \lambda Rx + \lambda alarm + \lambda LNA$$
$$\lambda R = (68.1 \times 10^{-6}) + (4.3 \times 10^{-6}) + (20 \times 10^{-6})$$
$$\lambda R = 92.4 \times 10^{-6}$$

The MTBF ($\theta R$) for redundant equipment is:

$$\theta_R = 1/\lambda_R = 1/(92.4 \times 10^{-6})$$

$$\theta_R = 10{,}823 \text{ hours}$$

The availability of the redundant equipment is calculated:

$$A_R = \theta_R/(\theta_R + MTTR)$$

Where MTTR = the actual switching time from the failed on-line receiver to the backup unit = 0.10 seconds = 0.000028 hours.

$$A_R = 10.823/(10{,}823 + 0.000028)$$
$$A_R = 0.999999997$$

which is virtually transparent.

Non, the non-redundant equipment failure rate ($\lambda NR$) is calculated:

$\lambda WGS$ = failure rate of waveguide switch
$\lambda CS$ = failure rate of coax switch
$\lambda PD$ = failure rate of power divider
$\lambda PS$ = failure rate of protection switch

$$\lambda NR = \lambda WGS + \lambda CS + \lambda PD + \lambda PS$$
$$\lambda NR = (.32 \times 10^{-6}) + (.55 \times 10^{-6}) + (.56 \times 10^{-6}) + (1.96 \times 10^{-6})$$

$$\lambda NR = 3.39 \times 10^{-6}$$

The MTBF ($\theta_{NR}$) for the non-redundant equipment is calculated:

$$\theta_{NR} = 1/\lambda NR = 1/(3.39 \times 10^{-6})$$

$$\theta_{NR} = 295{,}000 \text{ hours}$$

The availability of the non-redundant equipment is:

$$A_{NR} = \theta NR/(\theta NR + MTTR)$$

On an unmanned station MTTR = 24 hours, so

$$A_{NR} = 295{,}000/(295{,}000 + 24.0)$$
$$A_{NR} = 0.99992$$

The total equipment availability is:

$$A_{TOT} = [A_R][A_{NR}]$$
$$A_{TOT} = [0.999999997][0.99992]$$
$$A_{TOT} = 0.99992$$

The yearly unscheduled down time (Dt) is:

$$D_{(t)} = [1 - (A_{TOT})]\ 8760\ \text{Hours}/_{\text{Year}}$$

$$D_{(t)} = [1 - 0.99992]\ 8760\ \text{Hours}/_{\text{Year}}$$

$$D_{(t)} = 0.70\ \text{Hours}/_{\text{Year}}$$

These calculations assume that the failed receiver is repaired or replaced within 24 hours after switchover. The availability, however, is realistically dependent on the backup unit not failing during the downtime of the primary unit.

The mean time between a backup unit failure during the downtime of the primary unit ($\theta^1$) can be calculated as follows:

$$\theta^1 = (\theta_R)^2/Dt$$

Assume that repairs cannot be made for 24 hours or Dt = 24 hours.

$$\theta^1 = (10{,}823)^2/24$$

$$\theta^1 = 4{,}881{,}000 \text{ hours or } 557 \text{ years}$$

The availability due to a backup unit failure during the downtime of the primary unit ($A^1$) can be calculated as follows:

$$A^1 = \theta^1/(\theta^1 + Dt)$$

$$A^1 = 4{,}881{,}000/(4{,}881{,}000 + 24)$$

$$A^1 = 0.999995$$

$A^1$ is transparent when calculated in the total availability. The effect of $A^1$ is shown:

$$A_{TOT} = [AR]\quad [ANR]\quad [A^1]$$

$$A_{TOT} = [.999999997]\quad [.99992]\quad [.999995]$$

$$A_{TOT} = .999915$$

The downtime would be increased to only 0.74 hours.

**1:N Protection Switch's Availability Analysis**

Now consider one redundant receiver for "n" on-line receivers (1:n protection switch). The block diagram is shown in Figure 5 in which any 7 of the receivers must be operational.

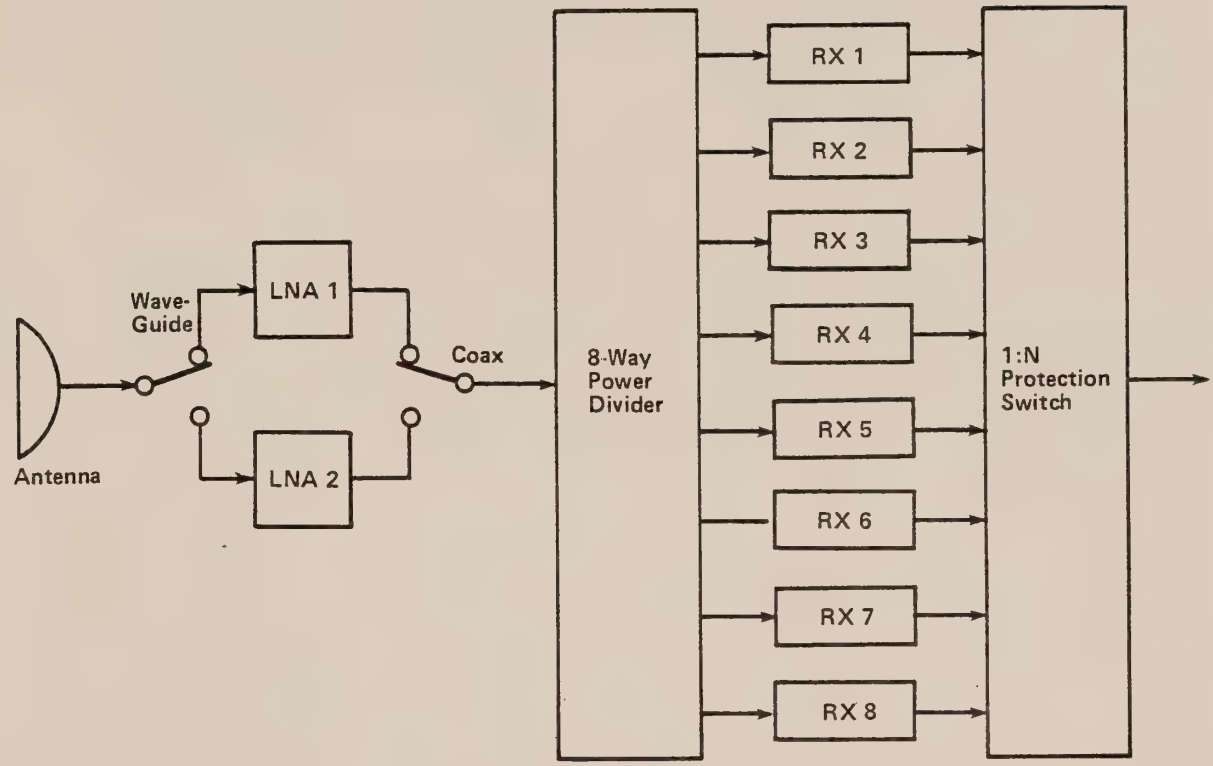



Figure 5. 1:7 Protection Switch

Assume RX 1 through RX 8 are Model 414 Video Receivers. The failure rates of the waveguide and coax switch are the same as those used in the 1:1 Protection Switching model. The failure rate for the 8-way power divider is typical. The 1:N Video Protection Switch is divided into nine blocks. Eight of these blocks are alarm blocks and are redundant. The protection switch block is non-redundant. The failure rates are calculated for Scientific-Atlanta's 1:N Video Protection Switch. The availability model reduces to that shown in Figure 6.

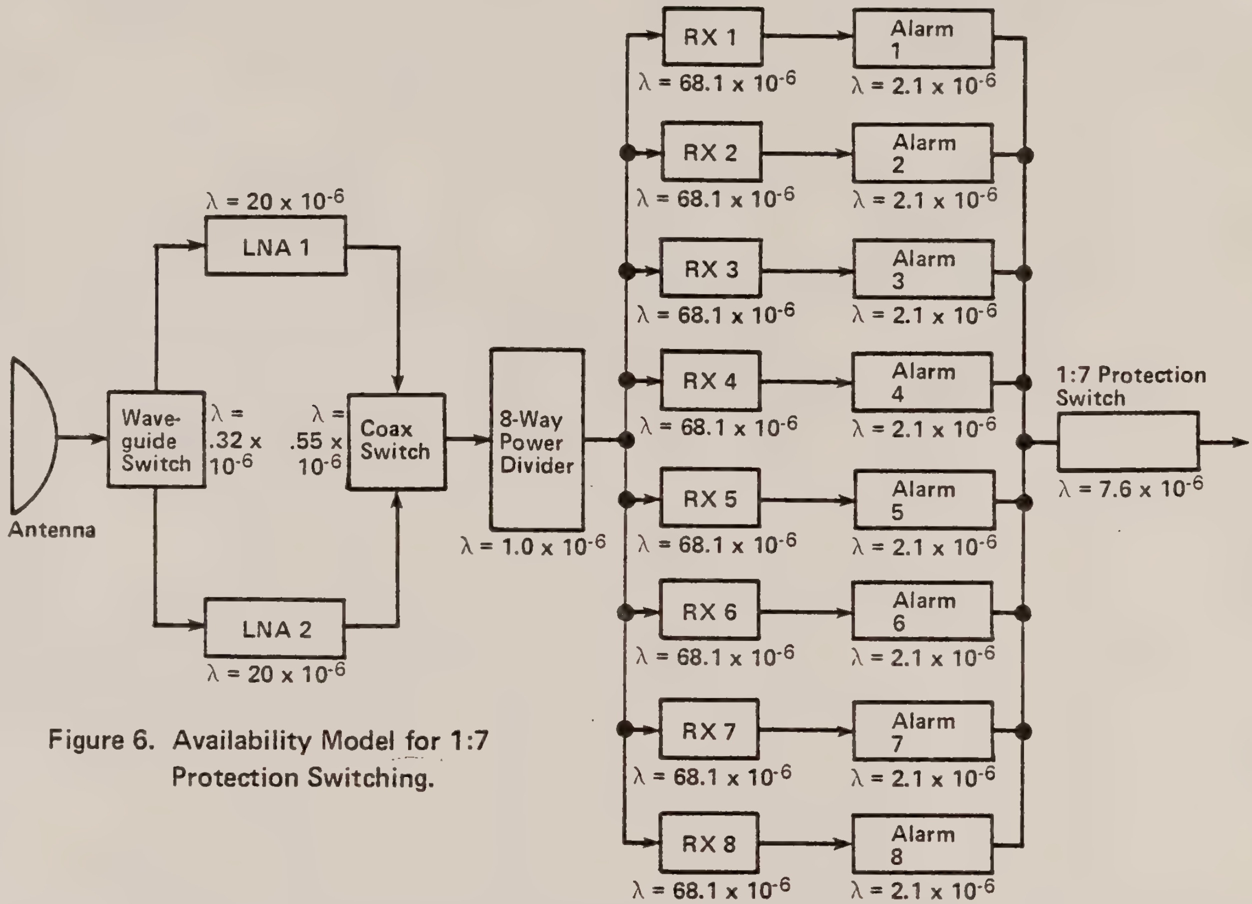



Figure 6. Availability Model for 1:7 Protection Switching.

Again, the model can be broken down into redundant and non-redundant equipment failure rates. The individual availabilities can be calculated, and the product taken to find the total availability.

First the redundant equipment failure rate ($\lambda R$) is calculated:

$$\lambda R = 7\ [\lambda Rx + \lambda ALARM] + \lambda LNA$$

$$\lambda R = 7\ [(68.1 \times 10^{-6}) + (2.1 \times 10^{-6})] + (20 \times 10^{-6})$$

$$\lambda R = 7\ (70.2 \times 10^{-6}) + 20 \times 10^{-6}$$

$$\lambda R = 511.4 \times 10^{-6}$$

The MTBF ($\theta R$) for redundant equipment is:

$$\theta R = 1/\lambda R = 1/(511.4 \times 10^{-6})$$

$$\theta R = 1955 \text{ hours}$$

The availability of the redundant equipment is calculated:

$$A_R = \theta R/(\theta_R + MTTR)$$

Where MTTR is the time to switch the 1:n protection switch, 0.25 SEC or 0.00007 hours. Then

$$A_R = 1{,}955/(1{,}955 + 0.00007)$$

$$A_R = 0.99999997$$

Now, the non-redundant equipment failure rate ($\lambda NR$) is calculated:

$\lambda WGS$ = failure rate of waveguide switch
$\lambda CS$ = failure rate of coax switch
$\lambda 8\text{-}PD$ = failure rate of 8-way power divider
$\lambda 1{:}7PS$ = failure rate of 1:7 protection switch

$$\lambda NR = \lambda WGS + \lambda CS + \lambda 8\text{-}PD + \lambda 1{:}7PS$$
$$\lambda NR = .32 \times 10^{-6} + .55 \times 10^{-6} + 1.0 \times 10^{-6} + 7.6 \times 10^{-6}$$
$$\lambda NR = 9.47 \times 10^{-6}$$

The MTBF ($\theta_{NR}$) for the non-redundant equipment is calculated:

$$\theta_{NR} = 1/\lambda\ NR = 1/(9.47 \times 10^{-6})$$
$$\theta_{NR} = 105{,}600 \text{ hours}$$

The availability of the non-redundant equipment is calculated:

$$A_{NR} = \theta_{NR}/\ (\theta = MTTR)$$

$$A_{NR} = 105{,}600/\ (105{,}600 + MTTR)$$

MTTR = 24.0 hours for an unmanned site.

$$A_{NR} = 105{,}600/\ (105{,}600 + 24.0)$$

$$A_{NR} = 0.99977$$

The total equipment availability ($A_{TOT}$) is:

$$A_{TOT} = [A_R]\quad [A_{NR}]$$

$$A_{TOT} = [0.99999997]\quad [0.99977]$$

$$A_{TOT} = 0.99977$$

The yearly unscheduled downtime (Dt), based on 24-hour a day operation is:

$$D_{(t)} = [1 - (A_{TOT})]\ 8760 \text{ Hours}/_{Year}$$

$$D_{(t)} = [1 - (0.99977)]\ 8760 \text{ Hours}/_{Year}$$

$$D_{(t)} = 2.00 \text{ Hours}/_{Year}$$

The availability, as in the 1:N protection switch, is dependent on the probability of the backup unit not failing during downtime of a primary unit. It is also dependent on any of the other 6 primary units not failing during the downtime. The term "double failure during downtime" will be used to indicate either of these situations occurring.

The mean time between double failure during downtime ($\theta''$) can be calculated as follows:

$$\theta'' = (\theta R)^2/n\ Dt$$

Assume that repairs cannot be made for 24 hours, or Dt = 24 hours:

$$\theta'' = (11{,}086)^2/(7)\ 24$$

$$\theta'' = 731{,}600 \text{ hours}$$

The availability due to a double failure during downtime (A'') can be calculated as follows:

$$A'' = \theta''/(\theta'' + Dt)$$

$$A'' = 731{,}600/(731{,}600 + 24)$$

$$A'' = .999967$$

A'' has little effect on the total availability. The total availability can be calculated:

$$A_{TOT} = [AR]\ [ANR]\ [A'']$$

$$A_{TOT} = [0.99999997]\ [0.99977]\ [0.999967]$$

$$A_{TOT} = 0.99974$$

The downtime would be increased to only 2.3 hours.

**Conclusions on Availability**

The comparative availabilities and downtimes summarized in Table 2 clearly indicate the value of redundance in the receive system.

| | Availability (A) | Downtime $(Dt)/_n$ |
|---|---|---|
| Receiver Alone | 0.9979 | 18.4 |
| Receiver with 1:1 Redundancy | 0.99992 | 0.70 |
| 7 Receivers with 1 Redundant Receiver | 0.99977 | 2.00 |

**Table 2.**

All availability calculations assume a 24 hour mean time to repair a failed unit. The yearly downtimes are based on 24-hour a day operation.

Failure of the backup units during downtime or failure of two units at the same time is not considered in Table 2. These situations have little effect on the system's availability and can be considered transparent.

A regularly scheduled maintenance program is essential for achieving the reliability just presented.

In Figure 7, yearly downtime is graphed as a function of time to repair a failed unit (MTTR). From the preceding discussion, Dt and MTTR can be related as follows:

For receiver system with no redundancy

$$Dt = [(1 - \theta \quad \theta + MTTR)]\ 8760 \text{ hours}$$

For 1:1 and 1:7 receiver systems

$$Dt = [1 - A_R\, \theta / (\theta + MTTR)]\ 8760 \text{ hours}$$

Where $A_R$ and $\theta$ are taken from earlier calculations.

Figure 7 clearly demonstrates the value of redundancy in terms of system downtime. Redundancy increases the total system's availability such that video traffic is virtually unaffected by unscheduled failures.

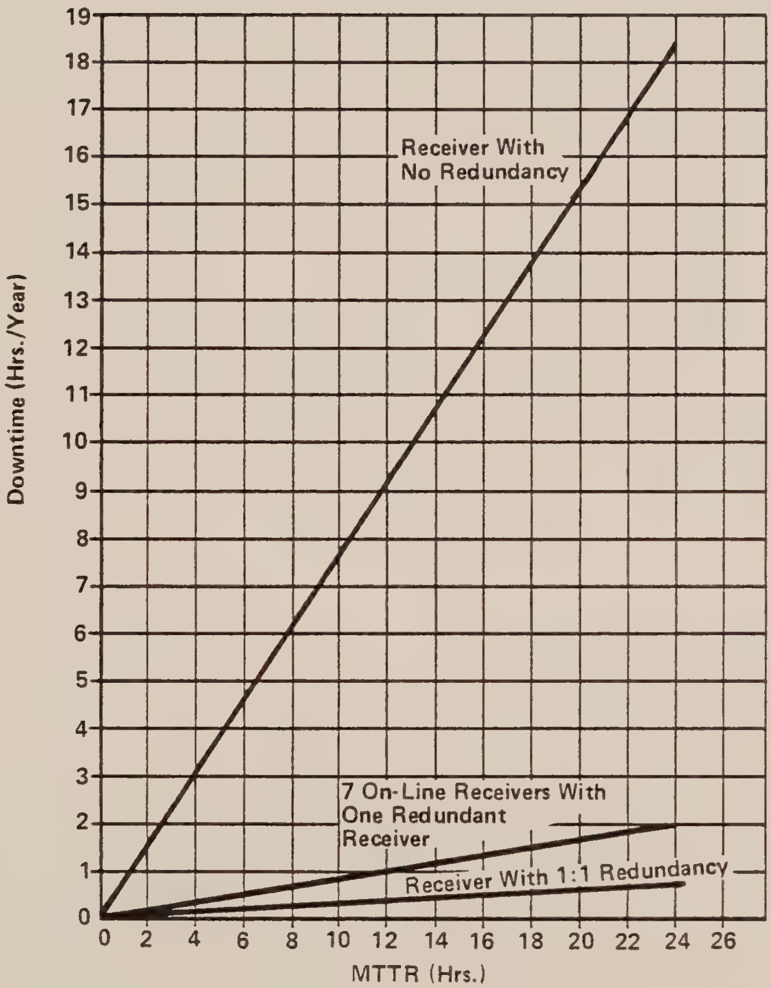



Figure 7. Downtime versus MTTR for Receivers With and Without Redundancy.

**Protection Switching**

Protection switching allows equipment which has failed to be automatically replaced by standby equipment. This replacement can be made so rapidly that the video and audio signal do not appear to be interrupted. Protection switching provides redundancy to the video receive system; therefore, the total systems availability is increased, and the maintenance downtime is minimized.

In a video receive earth station, the low noise amplifiers and video receivers are usually protected. The antenna is seldom protected due to its high reliability. The failure sensing circuitry of the protection switch senses key voltages and logic outputs from LNA's and receivers and determines whether switching should take place.

**1:1 Video Protection Switch**

The 1:1 Video Protection Switch is used with redundant receivers and can be used with redundant LNA's. Figure 8 is a function block diagram showing the 1:1 Protection Switch protecting both the LNA and video receiver. In order to simplify this discussion, each type of failure sensing and switching usually seen in a video receive earth station will be considered separately by function.

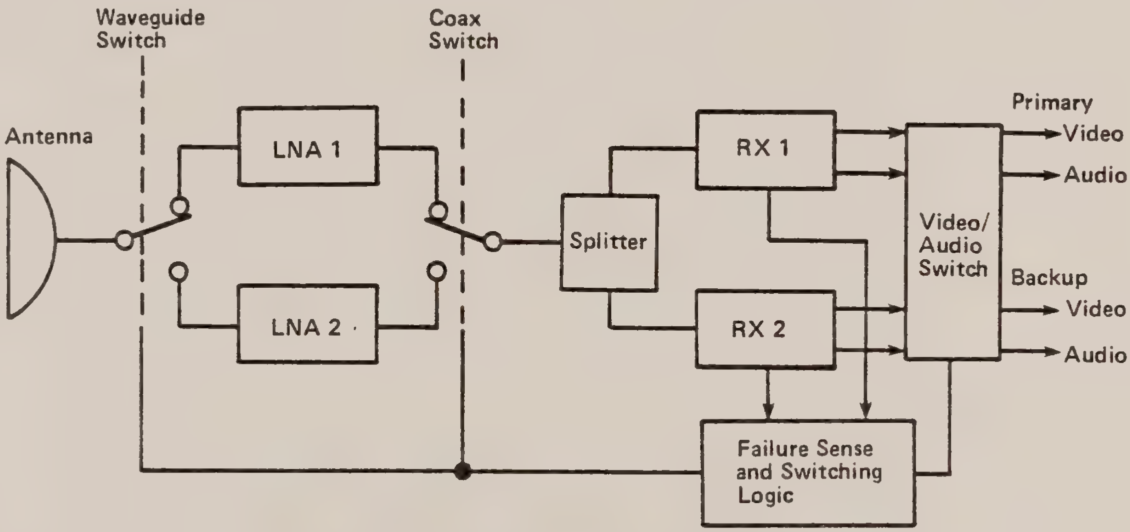



Figure 8. 1:1 Video Protection

When the LNA fails, both the RF input and the RF output must be switched. A waveguide switch is used on the input side, and a coax switch is used on the output side. The LNA, waveguide, and the coax switch are normally located in the antenna hub.

The degree of alarm monitoring varies with the LNA for both parametric amplifiers and FET amplifiers. For parametric amplifiers failure monitoring points may include power supplies, pump sources, temperature, and supply current. These monitoring points might be brought out individually or summarized into a single alarm output, FET type amplifiers have no sources, but they may also have built-in monitor points.

The protection switch can monitor the alarm monitor output from the LNA as well as the C/N indication from both receivers. If the LNA has no alarm monitor output, then only the C/N can be sensed. To use the C/N from both receivers, a threshold below 0 dB C/N is set. When the C/N goes below this level, both loss of signal and loss of noise is indicated. This indication means that the LNA has probably failed.

Receiver switching occurs at the video level, since both of the receivers are on-line to the RF, through the power splitter, at all times. The protection switch chooses from which receiver the video and audio output comes. If the primary receiver has failed, the protection switch makes the video and audio output of the backup receiver become primary.

In normal operation, the backup receiver is set to the receiver frequency of the primary receiver. Therefore, when the primary receiver fails the backup receiver's outputs will be the same program as the primary receiver. After the failure of the primary receiver has been corrected, the outputs are switched to their normal position automatically.

The protection switch could have features allowing the operator to force the primary outputs to be either the primary receiver or backup receiver, regardless of failures. The protection switch could force either LNA to be on-line regardless of failures. The operator could have the choice of allowing LNA 1 to be primary and LNA 2 to be backup or vice versa.

An important feature for the protection switch is not to switch to the backup receiver if it recognizes a failure in the backup receiver. In this case, the protection switch would keep the primary receiver on-line whether or not it fails. Under certain circumstances, both receivers may appear to fail. If the C/N indication is less than 0 dB, then the LNA has most likely failed, and the protection switch would switch to the backup LNA. If the C/N indication is close to 0 dB, then the signal from the satellite may be lost, due to a failure in the uplink to the satellite.

The protection switch typically monitors several key levels from the receiver to determine whether a receiver has failed. These levels may include C/N indication, first LO phase lock, second LO phase lock, subcarrier presence, video presence, and power supply voltages. These levels should be accessible from the video receiver. Voltage level sensing circuitry inside the protection switch determines whether each of these levels is within tolerance.

The reliability of a video receive earth station depends to a large extent on the reliability of the protection switch. The protection switch must be designed with reliability in mind. For example, the protection switch should have redundant power supplies. These power supplies can be diode combined.

A desirable option for the protection switch is remote manual control of switching. Remote manual control allows complete remote control of the front panel controls over a telephone line or microwave link. Forced switching of receivers or LNA's could be done in this manner.

**1:N Video Protection Switch**

A 1:N Video Protection Switch can back up many receivers. The exact number of receivers depends upon the capabilities of the protection switch and the decision of the operator. A greater number of receivers protected by one backup receiver causes a greater risk of two receivers failing and one being protected. However, protecting several receivers with one backup receiver is a great deal more economic than providing one for one protection for several receivers.

Although the 1:N Video Protection Switch is more complex than the 1:1 Video Protection Switch, it allows greater flexibility in a system. The backup receiver can be used to provide on-line video and audio outputs when no failures have occurred. The backup receiver can also be used to monitor channels which are on-line.

A 1:N Video Protection Switch can switch from primary to backup LNA in a manner similar to the 1:1 Video Protection Switch. Switching between receivers is more complicated than with the 1:1 Video Protection Switch. The monitoring of levels from the receivers is the same for the 1:N Video Protection Switch as the 1:1 Video Protection Switch, except for the number of receivers monitored. Figure 9 is a functional block diagram which shows the 1:N Video Protection Switch operating with seven receivers and one backup receiver.

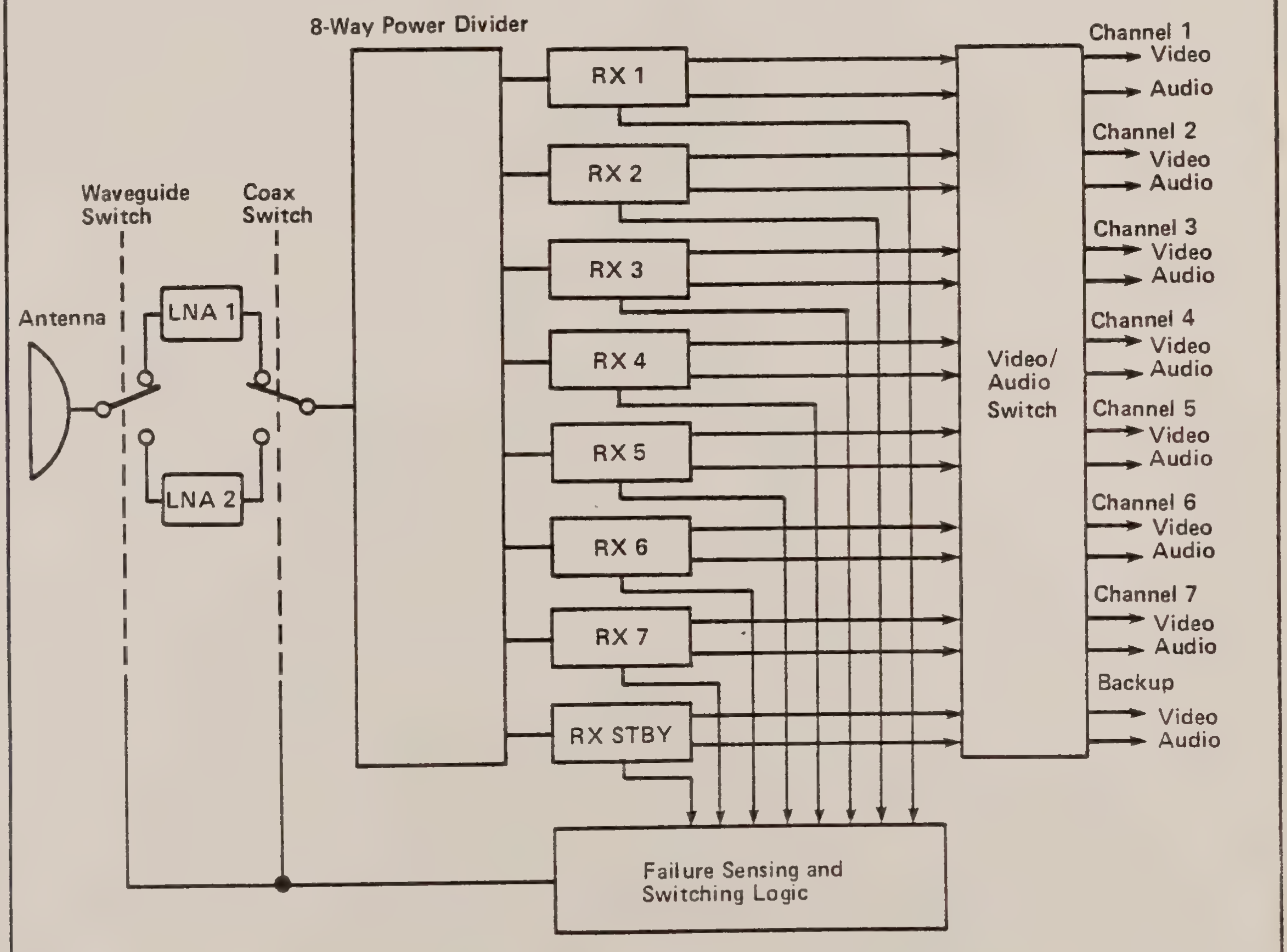



Figure 9. 1:7 Video Protection

A 1:N Video Protection Switch can be set up with a priority arrangement. One receiver known as Channel 1 will have the highest priority. The priority descends through as many as N receivers until the Nth receiver is reached, which has lowest priority. When any receiver fails, the backup receiver backs up the failed receiver. If another receiver fails, the backup receiver backs up the receiver with higher priority, and releases protection of the lower priority receiver. If any other receivers were to fail, the backup receiver would continue to back up the receiver with highest priority.

Receiver switching occurs at video level, since all the receivers are on-line to the RF, through a power splitter. When a receiver fails, the 1:N Video Protection Switch backs up the failed receiver's audio and video outputs with the audio and video outputs of the backup receiver. If the backup receiver fails, no switching occurs when another receiver fails. The 1:N Video Protection Switch must also set the backup receiver to the frequency of the failed receiver it backs up. If the backup receiver cannot switch to this frequency to back up the failed receiver, no switching occurs.

The frequency of each receiver on-line must be monitored in some manner. In Scientific-Atlanta's 1:N Video Protection Switch, these frequencies are monitored through seven thumbwheel switches on the front panel. The frequency for that particular channel is set on the thumbwheel switch for that channel. If the receiver for this channel fails and the 1:N Video Protection Switch chooses to back up this receiver, then the frequency of the backup receiver is set to the frequency on the thumbwheel switch.

The 1:N Video Protection Switch can have the feature of forcing certain channels to be backed up as well as releasing certain channels from becing backed up. Scientific-Atlanta's 1:N Video Protection Switch has a FORCE—PROTECT—RELEASE switch for each channel. When this switch is in FORCE, that channel's receiver is replaced by the backup receiver. If a channel of higher priority fails, the backup receiver replaces the higher priority receiver. The channel that is set to FORCE returns the original receiver on-line. If a channel lower in priority fails, the backup receiver remains on the forced channel. Therefore, the channels with lower priority are unprotected. When the switch is in RELEASE, that channel is unprotected. If the receiver of that channel fails, the backup receiver will not replace it. When the switch is in PROTECT, that channel is in the normal mode of operation. The channel will be protected by the backup receiver if a higher priority channel has not failed or is not forced.

Features can be added to a 1:N Video Protection Switch to make its operation more flexible. Scientific-Atlanta's 1:N Video Protection Switch has a MONITOR switch which sets the backup receiver to the transponder frequency selected by the MONITOR switch. When the backup receiver is used to monitor another channel, the backup receiver cannot protect any other channel. This feature is useful to verify proper operation of the backup receiver without disturbing on-line receivers. The BACKUP position is the normal position when protection is desired.

Alarm outputs can be brought out of the 1:N Video Protection to alert the operator of various conditions. Several conditions could even be sent over telephone line to another location, to warn the operator. One condition might be when a on-line receiver has failed and is being protected by the backup receiver. This condition signifies that further on-line receiver failures will cause loss of service. Another condition might be failure of the backup receiver. Again, on-line receiver failure will cause loss of service. A serious condition to report would be two receivers failing at the same time and loss of service.

The 1:N Video Protection Switch can monitor the alarm output from the LNA as well as C/N ratio from all receivers. If C/N is below a certain threshold below 0 dB for all receivers, then the LNA has failed.

The reliability of the 1:N Video Protection Switch is important. For this reason, it should have two power supplies. These power supplies can be diode combined.

## APPENDIX A

**1:1 Video Protection Switch Part No. 151723**

The 1:1 Video Protection Switch is a standard 19-inch rack mounted unit that is 3.50 inches high. The unit has a U-shaped aluminum chassis with all input/output connections on the rear panel. All operating controls and LED indicators are on the front panel. Figure 1A shows a view of the rear panel.

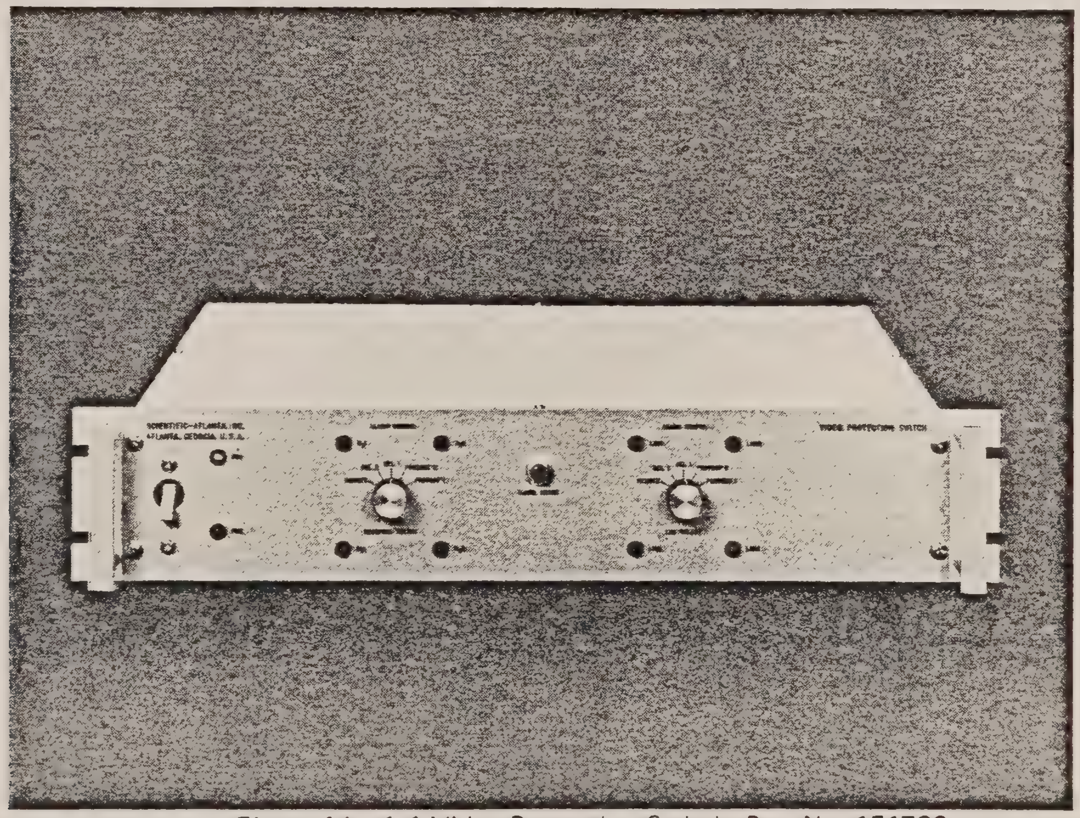


Figure 1A. 1:1 Video Protection Switch, Part No. 151723, Front Panel, Photo 9209

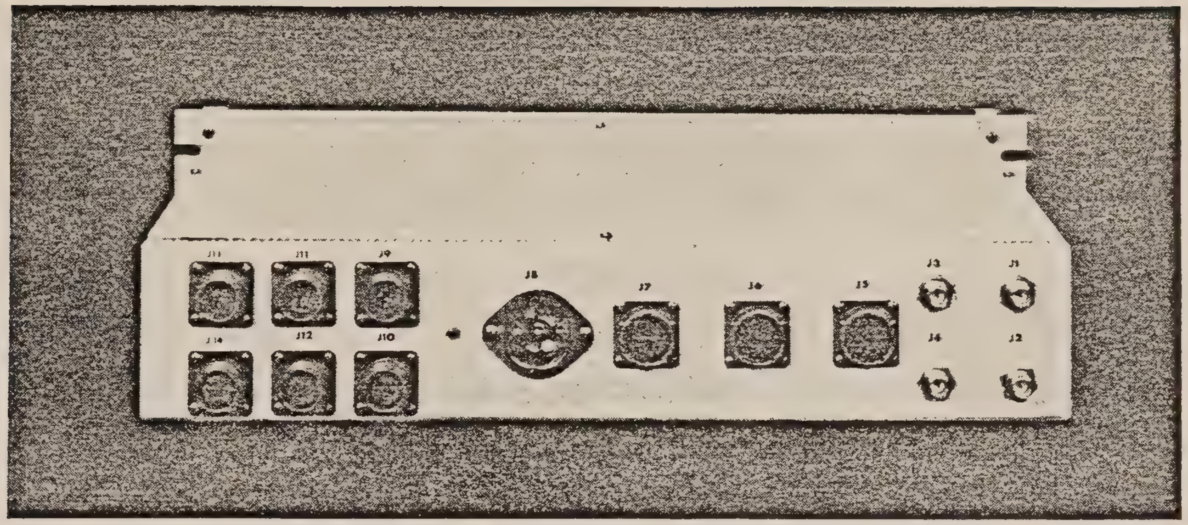


Figure 2A. 1:1 Video Protection Switch, Part No. 151723, Rear Panel, Photo 9210

The 1:1 Video Protection Switch provides automatic switching to standby equipment in the event of a failure of the on-line LNA or video receiver. It can be used with either the 411 Video Receivers or the 414 Video Receivers. Figure 3A shows how the 1:1 Video Protection Switch operates in a video receive earth station.

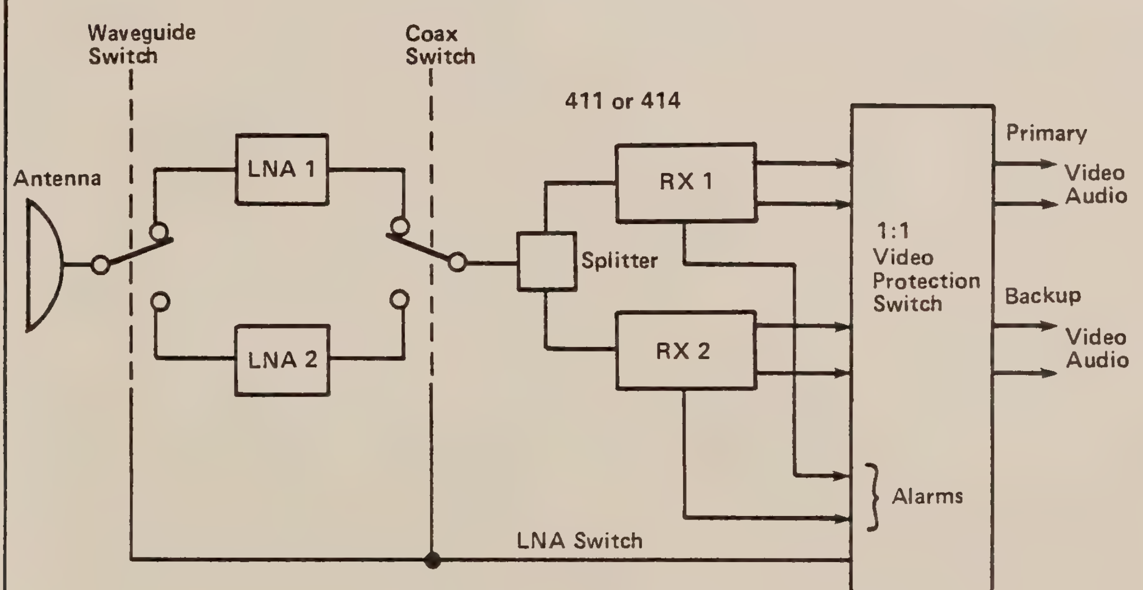



Figure 3A. 1:1 Video Protection Switch

Normally, the 1:1 Video Protection Switch will be operated in an automatic mode; however, the two receivers can be operated independently. When the receivers are operated independently, the primary channel is unprotected.

The power supply voltages, local oscillators, and C/N indications from both receivers are continuously monitored. If any one parameter is out of tolerance, the summary alarm for that particular receiver indicates an alarm state inside the protection switch. In automatic mode, switching to the backup receiver will occur.

The protection switch can select one of two LNA's as primary LNA. The other LNA is a backup unit. If the primary LNA fails, the backup unit is switched on-line. The backup LNA remains on-line until the protection switch is manually reset. The protection switch does not have the ability to know the status of a LNA which is not on-line.

Either LNA can be forced into operation without protection. The protection switch accepts failure alarms from the LNA and/or monitors C/N indications from both receivers.

Alarm indicators on the front panel are latching and must be reset manually. This feature provides detection of intermittent failures or failures which have been corrected.

The protection switch has redundant AC power supplies which are diode combined. Also, the protection switch can be operated from voltages available from the two receivers. This feature is convenient when the entire system is operated from DC power.

Certain controls on the front panel of the 1:1 Video Protection Switch can be operated by remote control. An operator at a remote location can force either receiver to be the primary receiver.

These controls can be operated over a telephone line or a wire line.

Table 1A lists the controls and indicators for the 1:1 Video Protection Switch. This table gives an indication of the flexibility of operation of this unit. Table 2A lists specifications of the 1:1 Video Protection Switch.

Table 1A, 1:1 Video Protection Switch Controls and Indicators

| Control/Indicator | Position | Function |
|---|---|---|
| ALARM RESET | | Pushbutton switch to reset the LNA switches and alarms after a fault has been cleared. |
| ALARM STATUS | LNA 1 | Illuminated (red) upon a failure of LNA 1. |
| | LNA 2 | Illuminated (red upon a failure of LNA 2. |
| ALARM STATUS | RX 1 | Illuminated (red) upon a failure of RX 1. |
| | RX 2 | Illuminated (red) upon a failure of RX 2. |
| LNA SELECT (switch) | REMOTE | LNA selection is remotely controlled. |
| | SEL 2 | LNA 2 is on-line with no protection. |
| | PROTECT 2 | LNA 2 is primary, and LNA 1 is backup. |
| | PROTECT 1 | LNA 1 is primary and LNA 2 is backup. |
| LNA SELECT (Indicators) | LNA 1 | Illuminated (green) when LNA 1 is on-line. |
| | LNA 2 | Illuminated (green) when LNA 2 is on-line. |
| Power Switch | Up | AC power applied to protection switch. |
| | Down | AC power removed from protection switch. |
| PS 1 | Green Illumination | Power Supply 1 is operating. |
| | Red Illumination | Power Supply 1 has failed. |
| PS 2 | Green Illumination | Power Supply 2 is operating. |
| | Red Illumination | Power Supply 2 has failed. |
| RECEIVER SELECT (Switch) | REMOTE | Receiver Selection is in remote manual control mode. |
| | SEL 2 | Outputs of RX 2 are switched to primary outputs. No switching occurs if RX 2 fails. |
| | SEL 1 | Outputs of RX 1 are switched to primary outputs. No switching occurs if RX 1 fails. |
| | PROTECT 2 | Parallel operation of RX 1 and RX 2 is not possible in normal operation.<br>RX 2's outputs are primary outputs. If RX 2 fails, RX 1's outputs become primary outputs. |
| | PROTECT 1 | Parallel operation of RX 1 and RX 2 is possible if no receiver fails.<br>RX 1's outputs are primary. RX 2's outputs are avilable as back-up. If RX 1 fails, RX 2's outputs become primary. |
| RECEIVER SELECT | RX 1 | Illuminated (green) when RX 1 is primary receiver on-line. |
| | RX 2 | Illuminated (green) when RX 2 is primary receiver on-line. |

Table 2A. 1:1 Video Protection Switch Technical Characteristics

| Characteristic | Specification |
|---|---|
| ALARM INPUTS LNA | LNA failure detected by internal sensor (when included in LNA) |
| | Negative C/N level in both receivers. (Threshold should be below 0 dB. 0 dB is reference for no carrier, −4 dB typical.) |
| Receiver C/N | +10 dB Adjustable. |
| Receiver Downconverter Status | Loss of local oscillator lock (voltage level from local oscillator) |
| Receiver Power Supply | ±10% deviation of voltage level |
| POWER REQUIREMENTS | 115V ac ±10% |
| | Power supplied from two receivers for DC operation. |
| SIZE | 19 inches wide, 3.5 inches high, and 15 inches deep. |
| SWITCHOVER TIME | |
| Receiver | 100ms (maximum) |
| LNA | 250ms (maximum) |
| WEIGHT | Less than 10 pounds |

## APPENDIX B

**1:N Video Protection Switch Part No. 154361.** The 1:N Video Protection Switch is a standard 19-inch rack mounted unit that is 7.00 inches high. The unit has a U-shaped aluminum chassis with all input/output connections on their rear panel. All operating controls and LED indicators are on the front panel. Figure 1B shows a view of the front panel. Figure 2B shows a view of the rear panel.

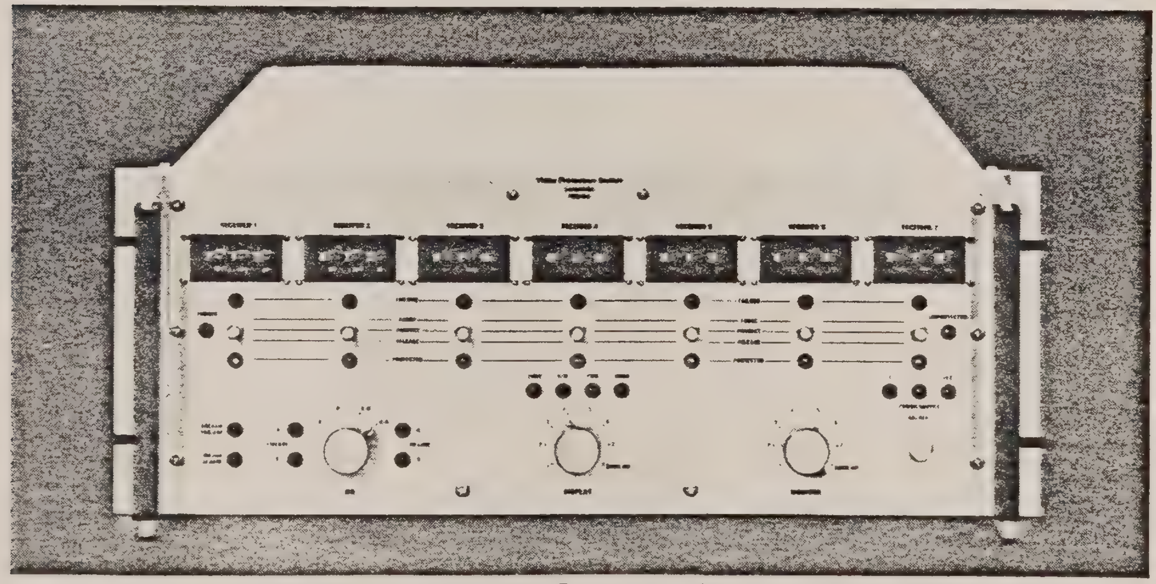


Figure 1B. 1:N Video Protection Switch, Part No. 154361, Front Panel, Photo 9207

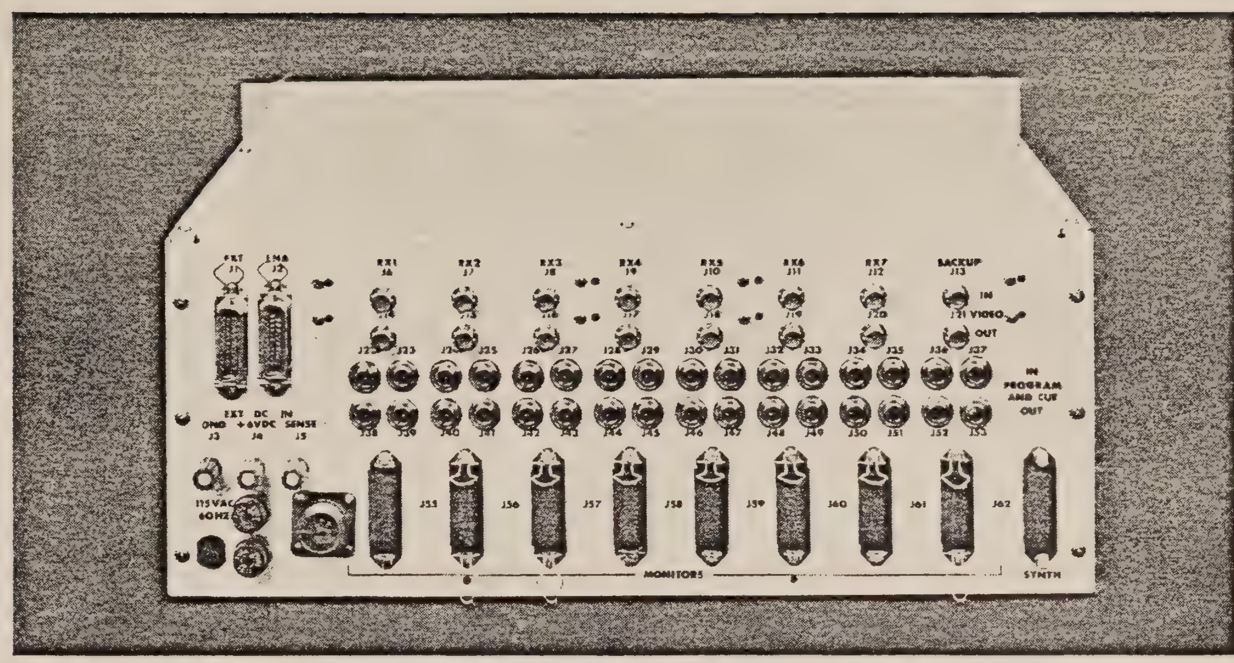



Figure 2B. 1:N Video Protection Switch, Part No. 154361,
Rear Panel, Photo 9208

The 1:N Video Protection Switch provides automatic protection for up to seven receivers with one backup receiver. It can be used with either 411 Video Receivers or 414 Video Receivers. A mixture of 414 and 411 receivers can also be used. LNA protection can be provided as an option. Figure 3B shows how a 1:N Video Protection Switch can be used in a video receive earth station with seven on-line receivers and one backup receiver.

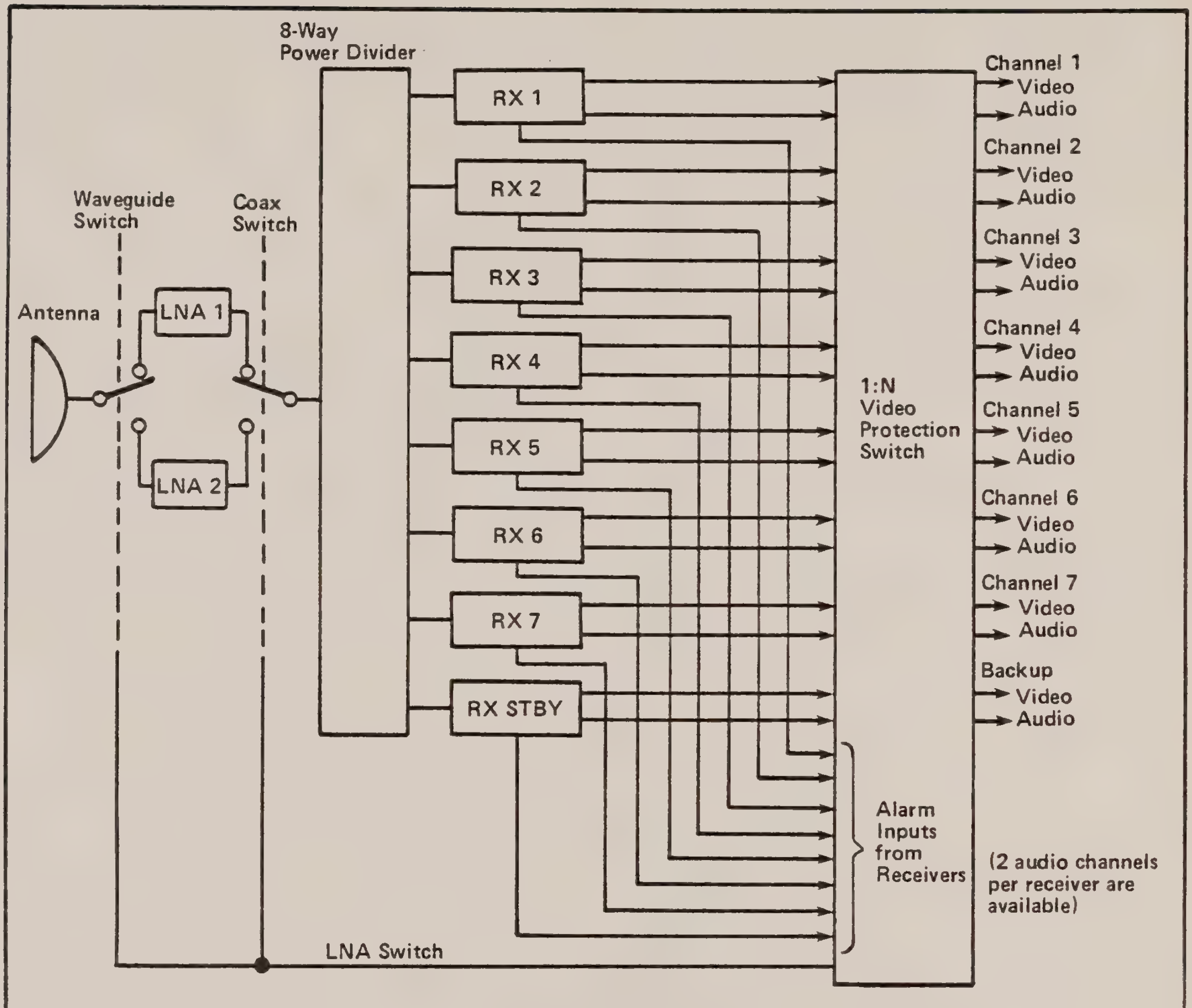



Figure 3B. 1:N Video Protection Switch.

The 1:N Video Protection Switch is normally set up in a priority arrangement as described in preceding discussion. In this arrangement Channel 1 has highest priority and Channel 7 has least priority. The backup receiver provides an additional on-line receiver as long as no failures occur.

The FORCE—PROTECT—RELEASE switch allows the operator to force backup of an on-line receiver with the backup receiver. The operator may also keep a receiver from being backed up when it fails by the use of this switch.

The 1:N Video Protection Switch continuously monitors power supply voltages, local oscillators (downconverter's status), C/N indications, and video level (for 414 receiver only). If any one parameter is out of tolerance, the summary alarm for that particular receiver indicates an alarm state inside the protection switch and switching may occur. Some of these levels differ between the 411 Video Receiver and the 414 Video Reciever.

An option is available which allows the 1:N Video Protection Switch to protect the LNA. This protection is similar to the operation of the 1:1 Video Protection Switch. If the backup LNA is switched on-line, it must remain on-line until the protection switch is manually reset. The protection switch does not have the ability to know the status of a LNA which is not on-line.

The FAILURE indicators for each receiver channel are latching indicators. They will remain illuminated until reset by placing the FORCE–PROTECT–RELEASE switch to RELEASE position. The LNA FAILURE indicators also latch. They must be reset manually.

The 1:N Video Protection Switch has redundant AC power supplies which are diode combined. Redundant DC input power supplies can be provided as an option. External power may also be provided.

Major and minor alarm relay contacts are available. These contacts can be used to signal the operator of a major or minor alarm condition. A major alarm occurs if a receiver fails and no backup occurs, a minor alarm occurs if a receiver fails and is protected by the backup receiver.

The 1:N Video Protection Switch can switch two different audio outputs for each receiver. This feature is useful if a cue channel is present or stereo audio output is desired.

Table 1B lists the controls and indicators for the 1:1 Video Protection Switch. This table gives an indication of the different operations available from the 1:N Video Protection Switch. Table 2B lists specifications of the 1:N Video Protection Switch.

Table 1B. 1:N Video Protection Switch Controls and Indicators.

| Control/Indicator | Position | Function |
|---|---|---|
| BACKUP FAILURE | | Illuminated (red) upon failure of backup receiver. |
| DISPLAY (switch) | 1 – 7 | CONV., C/N, PWR, and VIDEO indicators give status of Receiver 1 through Receiver 7, depending upon position of switch. |
| | Backup | CONV., C/N, PWR, and VIDEO indicators give status of backup receiver. |
| DISPLAY (Indicators) | CONV. | Illuminated (red) upon failure of down-converter in receiver. |
| | C/N | Illuminated (red) upon failure of receiver due to C/N level. |
| | PWR. | Illuminated (red) upon failure of power supply in receiver. |
| | VIDEO | Illuminated (red) upon failure of receiver due to video level. |
| FORCED | | Illuminated (yellow) when FORCE–PROTECT–RELEASE switch is in FORCE position for one or more receivers. |

Table 1B. 1:N Video Protection Switch Controls and Indicators. (continued)

| Control/Indicator | Position | Function |
|---|---|---|
| LNA (switch) | A | LNA A is on-line with no protection. |
| | B | LNA B is on-line with no protection. |
| | A – B | LNA A is primary LNA with LNA B as backup LNA. |
| | B – A | LNA B is primary LNA with LNA A as backup LNA. |
| FAILURE (LNA Indicator) | A | Illuminated (red) if LNA A has failed (latching indicator) |
| | B | Illuminated (red) in LNA B has failed (latching indicator) |
| ON-LINE (LNA Indicator | A | Illuminated (green) if LNA A is on-line. |
| | B | Illuminated (green) if LNA B is on-line. |
| MAJOR ALARM | | Illuminated (red) when a receiver fails and no backup is provided. |
| MONITOR | 1 – 7 | Switches frequency of backup receiver to frequency of Receiver 1 through Receiver 7 depending on position of switch. (In these positions, no receivers are protected) |
| | BACK UP | Normal Position. Backup Receiver can protect those receivers for which protection is desired. |
| ON/OFF (Power Switch) | ON (Illuminated) | Power is applied to protection switch. |
| | OFF (not Illuminated) | Power is removed from protection switch. |
| POWER SUPPLY | 1 | Illuminated (green) power supply 1 is operating |
| | 2 | Illuminated (green) power supply 2 is operating |
| | EXT. | Illuminated (green) external power is applied. |
| UNPROTECTED | | Illuminated (yellow) means that a condition exists such that one or more receivers are unprotected. |
| The following Controls/Indicators are under RECEIVER 1 through RECEIVER 7 (these controls/indicators have the same function for each of seven receiver positions) | | |
| Frequency Thumbwheel | | Displays frequency to which back-up receiver will go, when replacing that receiver. (Normally set to the same frequency that receiver on-line is set). |

Table 1B. 1:N Video Protection Switch Controls and Indicators. (continued)

| Control/Indicator | Position | Function |
|---|---|---|
| FAILURE | | Illuminated (red) when that receiver has failed (latching) |
| FORCE—PROTECT—RELEASE Toggle Switch | FORCE | Backup receiver is forced to replace this receiver as long as a receiver with higher priority does not fail. |
| | PROTECT | Normal Position — This receiver is protected. |
| | RELEASE | Receiver will not be replaced by backup receiver if it fails. |
| PROTECTED | | Illuminated (yellow) means that receiver is being replaced by backup receiver. |

Table 2B. 1:N Video Protection Switch Technical Characteristics.

| Characteristic | Specification |
|---|---|
| ALARM INPUTS<br>LNA | LNA failure detected by internal sensor (when included in LNA) |
| | Negative C/N level in both receivers. (Threshold should be below 0 dB. 0 dB is reference for no carrier —4 dB is typical setting) |
| Receiver C/N | +10 dB Adjustable. |
| Receiver Downconverter Status | Loss of local oscillator lock (voltage level from local oscillator) |
| Receiver Power Supply | ±10% deviation from voltage level. |
| Receiver Video Level | Less than .7V p-p Adjustable (414 Video Receiver only) |
| POWER REQUIREMENTS | 115V ac ±10% or —24V dc nominal (-19 to -40V dc) |
| SIZE | 19 inches wide, 7 inches high, 19 inches deep. |
| SWITCHOVER TIME | |
| Receiver | 100 ms (maximum) |
| LNA | 250 ms (maximum) |
| WEIGHT | Less than 15 pounds. |

BIBLIOGRAPHY

1. Fonda, Fred; Hart, Jim; and Warren, Fred, "CATV Earth Station Reliability". SCTE Reliability Conference, Atlanta, GA, Scientific-Atlanta, Inc., 1976.
2. U.S. Department of Defense, Military Standardization Handbook, "Reliability Prediction of Electronic Equipment", MIL-HDBK-217B, Washington, D.C., U.S. Government Printing Office, 1974.
3. Williams, Tom, "Protection Switching", Earth Station Technology Conference, Atlanta, GA, Scientific-Atlanta, Inc., 1976.

# REMOTE CONTROL & MONITORING CONSIDERATIONS

Thomas M. Williams
Senior Engineer
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## REMOTE CONTROL AND MONITORING CONSIDERATIONS

Remote monitoring and control of unmanned earth stations may be used for convenience and/or to satisfy FCC requirements. Generally only those unmanned stations equipped with uplink capability will be required by the FCC to be remotely controlled. Remote functions fall into three categories:

- Alarm and Status Monitoring
- Analog Value Monitoring
- Control Execution

Alarm and status monitoring provides both indication of failure in earth station components through the use of summary alarms and status of earth station functions (usually switches). Status information is also used to confirm that control functions have been executed.

Two basic types of control and monitoring systems may be used. Some systems use dedicated phone lines to report real time information to the control terminal. This type of equipment is especially useful for transmit stations with motor drives because uplink power and antenna position can be constantly monitored to avoid microwave radiation hazard. Other systems may use a non-dedicated phone line. These units phone a central unit when an alarm occurs and give status report to the unit or operator on duty. This report will contain only the information that a particular alarm has occurred and when it occurred. Constant monitoring is not possible with this system. Also some equipment of this type allow the operator to phone the remote unit at the earth station to receive periodic status and give commands to the station. This type of equipment is more useful for receive-only earth stations since no personal danger is involved with antenna position at the receive-only station.

A typical alarm and status system is shown in Figure 1. Each alarm or status point is assigned a bit in the telemetry word. This word is then sent by 3 kHz bandwidth FSK transmitter over a dedicated phone line or microwave sub-carrier to the manned control center. Each alarm or status may then be displayed on a status board or CRT terminal.

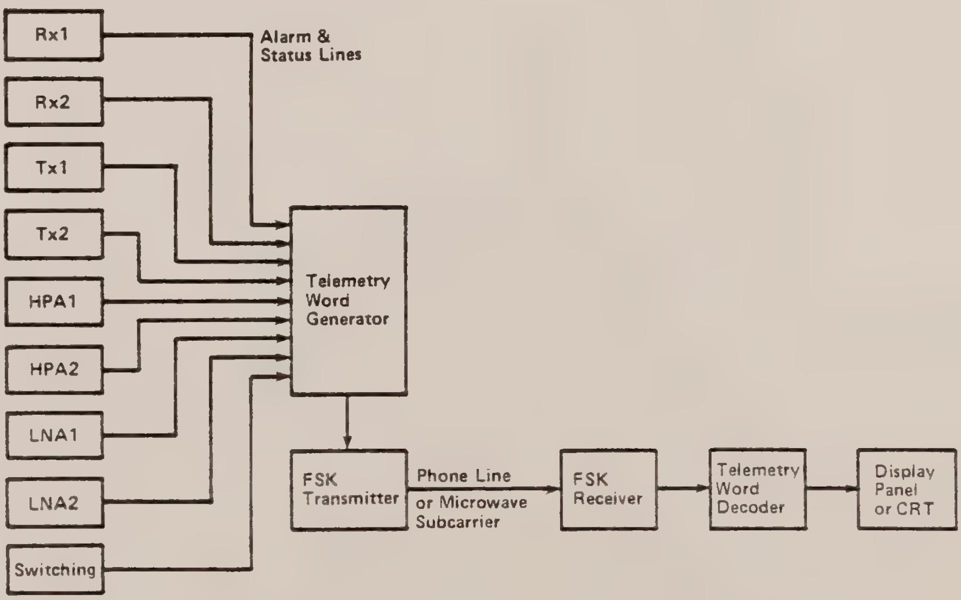



Figure 1. Remote Alarm & Status System.

Typical alarm functions which might be monitored include:

- **High-Power Amplifier (HPA)**
  - Output Element Temperature
  - Reflected RF Power Excessive
  - Body Current
  - Beam Current
  - Air Flow
  - Interlock
  - Filament Power Supply
  - Summary Alarm
- **Low-Noise Amplifier (LNA)**
  - Temperature (Hi-Lo)
  - Pump Source Alarm
  - Power Supply Alarm
  - Summary Alarm
- **Exciter (Tx)**
  - Supply Voltages
  - LO Phase Lock
  - Deviation
  - Dispersal
  - Pilot Level
  - Summary Alarm
- **Receiver (Rx)**
  - Supply Voltage
  - C/N Ratio
  - LO Phase Lock
  - Subcarrier Presence
  - Video Presence
  - Summary Alarm
- **Shelter**
  - Temperature Alarm
  - Smoke Alarm
  - Entry Alarm
  - AC Power Fail
- **Switching Functions**
  - LNA On-Line
  - HPA On-Line
  - Baseband Switch Position
  - Microwave Link Position
  - Exciter Switch Position
- **Antenna**
  - Position Limits

Analog measurements can be made at the earth station, converted to a digital code and telemetered back to the manned control center in much the same way as status and alarm points. This system is shown in Figure 2. Each monitor point is assigned a name code in the telemetry word such that analog values for various point are not confused. The digital value is applied to either D/A converter for analog meter display or a digital readout meter. Points that might be monitored are:

- HPA Power
- Total Transmit Feed Power
- Antenna Position
- TWT Power
- Exciter Power Output
- C/N Ratio
- Antenna Motion

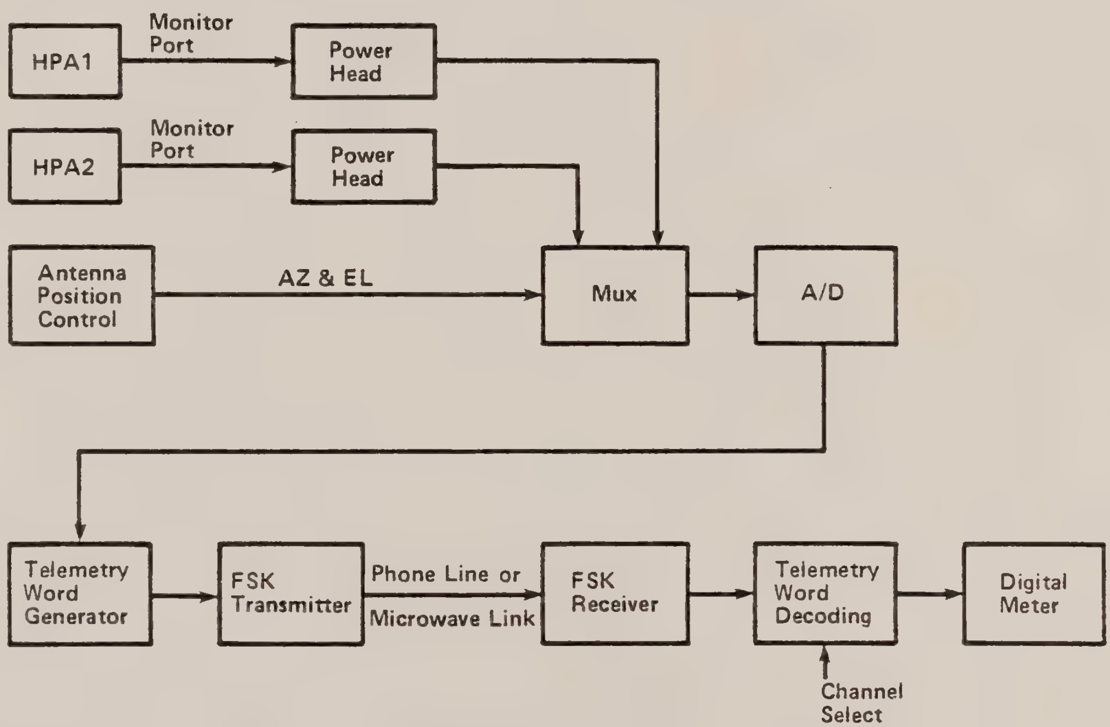



Figure 2. Analog Monitoring System

Remote earth station control involves the sending of a coded message from the central control station to the unmanned location. An example of this system is shown in Figure 3. The digital control word is decoded by the remote station equipment with each control point individually selected. An execute command from the control station actually activates the control circuitry. Typical control functions include:

- HPA Power Control
- Antenna Position
- Baseband Switching
- LNA Selection
- Exciter Selection
- HPA Overload Reset
- Microwave Feed Select
- HPA Beam On/Off

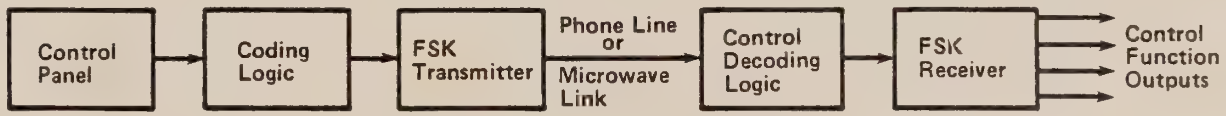



Figure 3. Control System

The alarm, status, and control points given in the above examples should not be considered to be all-inclusive. Each station or system will have its own unique requirements and specification. Fortunately equipment of this type comes in almost any desired configuration. System size can vary from a status and alrm system at a redundant R/O to a complete control and monitoring system for a large earth station with several up- and down-links.

# RECEIVE ONLY EARTH STATION INSTALLATION

Fred A. Smith
Applications Engineer
Cable Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

# RECEIVE ONLY EARTH STATION INSTALLATION

**Introduction** The purpose of this paper is to describe, in general terms, the requirements for and procedures used in the construction of Scientific-Atlanta's 5 Meter and 10 Meter Receive Only Earth Stations. Routine maintenance will also be discussed.

**Foundation** The foundation is an essential element of the total antenna installation. The foundation must be oriented so that the desired pointing angles can be achieved. It must be able to withstand the maximum loads exerted on it and be stiff enough to maintain the proper pointing angle.

It is imperative that the owner of an antenna satisfy himself through the use of competent engineering assistance, that the foundation is properly designed for his particular application and the local building codes. As an assistance, typical foundation plans are provided by Scientific-Atlanta (see Attachment A); however, Scientific-Atlanta does not represent or warrant that a particular design or size of foundation is appropriate for any particular locality or installation.

The most accurate way of laying out the pad center line or heading is by using a Polaris observation to determine true north and then locating the pad centerline (proper angle data is supplied by Scientific-Atlanta) in reference to true north.

Proper location of the anchor bolts prior to pouring the pad is critical. These bolts must be in the correct positions in order for the antenna to be properly assembled and pointed. Scientific-Atlanta provides a Template Assembly consisting of precision fabricated metal parts which when assembled can be used to accurately establish the anchor bolts in the foundation forms. Special note should be made of the "CAUTIONS" contained in the installation instructions to prevent damaging the anchor bolts.

Prior to pouring the pad or foundation, provisions should also be made for providing AC voltage at the pad and RF cable interface between the pad and the headend building. This can easily be accomplished through the use of 4" PVC pipe.

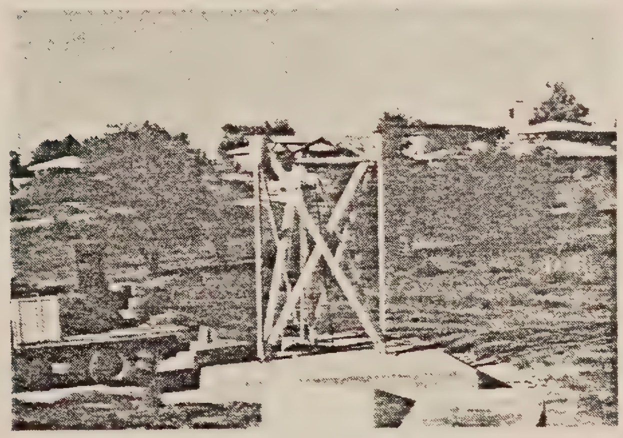
**10M Construction** It is important that the entire system assembly instructions be read completely and thoroughly understood before attempting to assemble any part of the system.

Some type of lifting device will be required to assemble the antenna system. Whether or not a crane or the Model 8092 Hoist Assembly, with or without the Model 8091 Assembly Platform, is used, the system must be assembled in specific order.

Assembly Outline:
This is a general procedure for the construction of a 10 Meter, Receive Only Earth Station. The visual aids and discussion that make up this presentation will expand on the construction procedure.

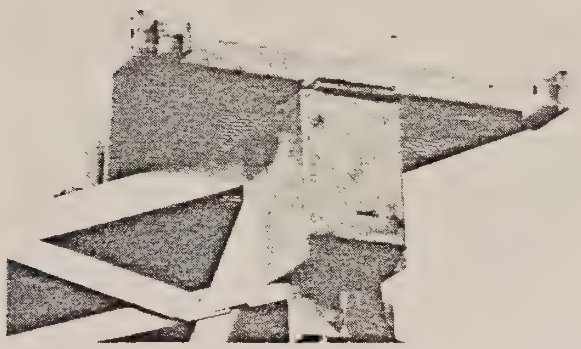
1. Inspect, account for and organize all parts of the system.
2. Install and level the three base plates, making sure they are in the proper positions.

3. Base plate No. 1 is a base plate/bearing combination.
4. Attach leg No. 1 to base plate/bearing assembly.
5. Attach legs No. 2 and No. 3 to their respective base plates.
6. Loosely attach two of the six cross braces to the tops of each of the three legs per instruction manual.
7. Using a bucket truck or similar lifting device, lift leg No. 1 into position.
8. Lift leg No. 2 and No. 3 into their respective positions.
9. Loosely attach cross braces.
10. Loosely attach three horizontal braces in proper sequence.
11. Lift three upper angles into position and loosely attach.
12. Lift six diagonal braces and loosely attach in the proper sequence.
13. Install three cap angles in the proper positions.

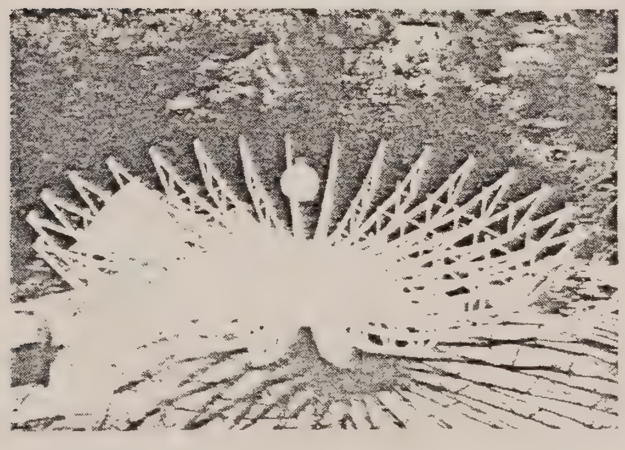


14. Loosely attach rub strip support, center deck support, and the LH/RH deck platforms.
15. Lift upper azimuth bearing housing and loosely attach.
16. Perform the specified torque down sequence on the mount.

17. Lift and install "A" frame assembly.



18. Install lower azimuth bearing housing to base plate/bearing No. 1.
19. Attach elevation actuator assembly to lower azimuth bearing housing.
20. Install azimuth actuator assembly – usually attached to Leg No. 2.
21. Inspect hub, trusses, and spars.
22. Attach trusses to hub; note close tolerance machining on mating surfaces.



23. Inspect panels for damage.
24. Install panels; do not tighten bolts.

25. Installing the last panel may require some adjustment. Follow proper torquing sequence after all the panels are installed.
26. Install the feed assembly carefully per instruction manual.
27. Using <u>only</u> nylon lifting straps, lift the hub and reflector assembly into position and attach to "A" frame. Do not remove crane from reflector.

28. Install LH and RH "A" frame support struts and tighten all bolts.
29. Attach elevation actuator to hub and remove crane.
30. Install LNA and connect the power and RF cables to the LNA. Also connect pressurization system.
31. Properly position the antenna in both azimuth and elevation.

For a 4-man crew, all of the assembly can be completed in three eight-hour days.

**5M Construction**

It is important that the entire system assembly instructions be read completely and thoroughly understood before attempting to assemble any part of the system. Particular attention should be paid to all "NOTES" and "CAUTION."

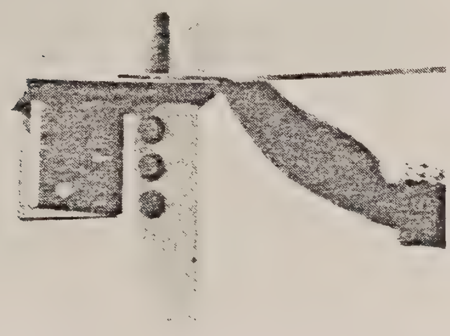
A lifting device will be required to assemble the antenna system. Either a crane or the Model 8096 Erection Kit may be used.

The assembly of the antenna can be divided into three segments:
1. Mount
2. Reflector
3. Feed

The assembly segments can be accomplished independently of each other with the exception that when the Erection Kit is to be used, the reflector must be assembled near the mount.

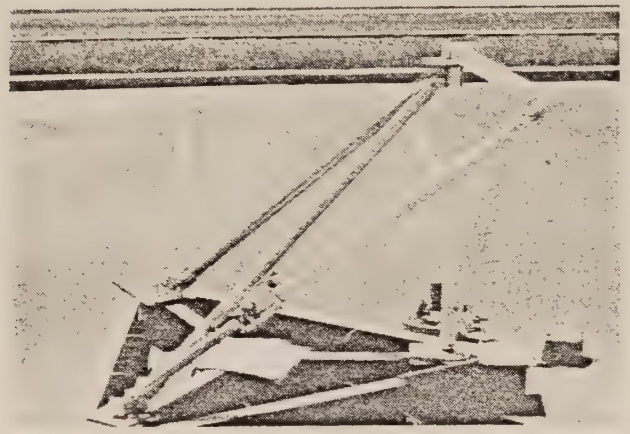
Assembly Outline:
This is a general procedure for the construction of a 5 Meter, Receive Only Earth Station. The visual aids and discussion that make up this presentation will expand on the construction procedure.

1. Inspect, account for and organize all parts of the system.
2. Install the three base plates onto the prepared foundation at their proper locations. These base plates should sit flat on the foundation and be level with respect to each other. If the foundation is not level, the pads should be shimmed or grouted.
3. Install anchor bolt nuts (on top of base plates) and washers, but do not torque them.
4. Attach the kingpost to the front kingpost bearing after liberally greasing the bearing.
5. Assemble the leg juncture (clevis), trunnion support, and support to kingpost brace. Note that the three bolts that hold the trunnion support in the kingpost must have the nuts facing forward toward the reflector.



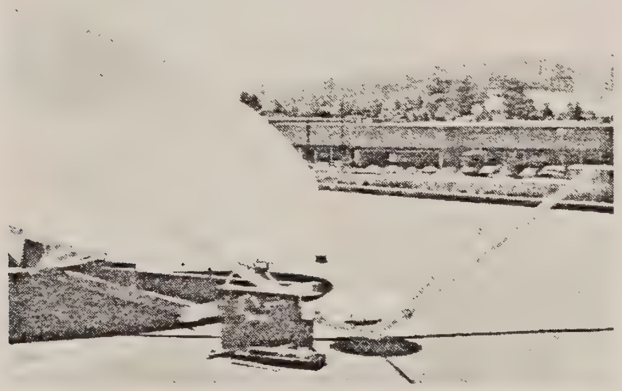
6. Assemble the two rear legs making sure that they attach to the outside of the mating parts of both ends. Bolt placement at the leg juncture is also important.

7. Attach the azimuth actuator assembly to the mount. The actuator will be attached to the left rear leg for use with SATCOM I.

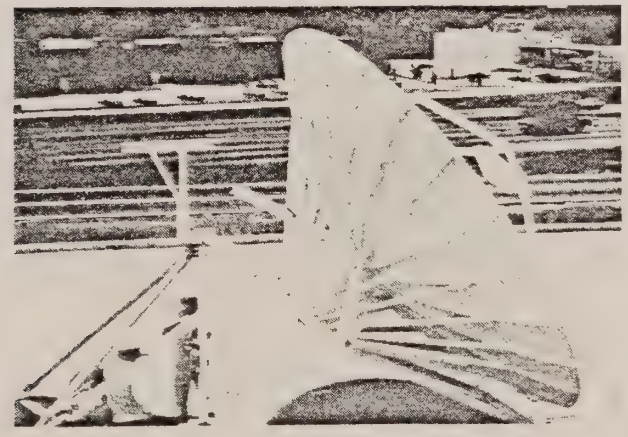


8. Tighten all mount fasteners as indicated in the installation instructions.
9. Assemble the elevation actuator mechanism and attach it to the mount.
10. The reflector should be assembled in an upright configuration, i.e., facing straight up.
11. Attach the hub cover to the hub.
12. Attach the horizontal reflector support to the hub. This piece should extend toward the right.
13. Attach the two hub braces to the hub.
14. Attach the panel-to-hub struts to the beveled, bottom surface of the hub.
15. Block up the hub so that the upper surface (where the panels attach) is level.
16. Attach the panels one at a time, first to the hub and then to the adjacent panel flange and the panel strut. Refer to the 5 Meter reflector assembly instructions for the correct order and angular orientation.

17. The final panel may be difficult to install and general adjustment of the other panels may be required.
18. Tighten all fasteners. Be sure to tighten the panel fasteners in the proper sequence.
19. Assemble the subreflector and three spars.

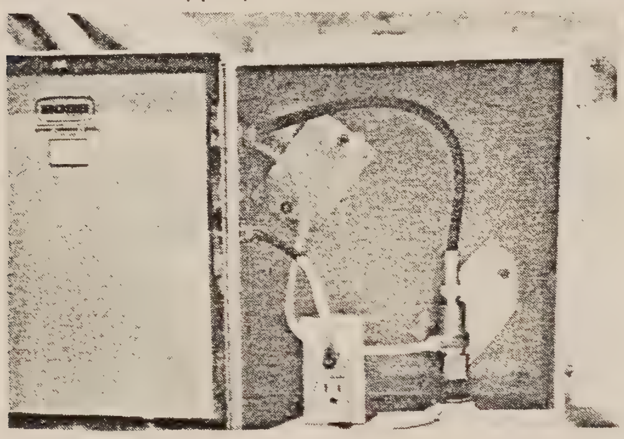


20. Lift the subreflector assembly and attach it to the assembled reflector.
21. Using either the Erection Kit or a crane, bring the reflector into position to be mated to the mount. Attach the reflector to the mount.



22. Attach the elevation actuator assembly to the hub before releasing the reflector from the crane or the erection kit.
23. With the antenna lowered to the minimum elevation angle, install the Feed Assembly.
24. Install the LNA.

25. Make the appropriate electrical, RF, and pressurization connections.



26. Properly position the antenna in both azimuth and elevation.

For a crew of three workmen, all of the assembly can be completed in an eight hour day.

**Maintenance** The following maintenance operations should be performed at the prescribed time interval:

Each Month:

1. Drain pressurization system balast tank.
2. Check desicant.
3. Check pressurization system for leaks.

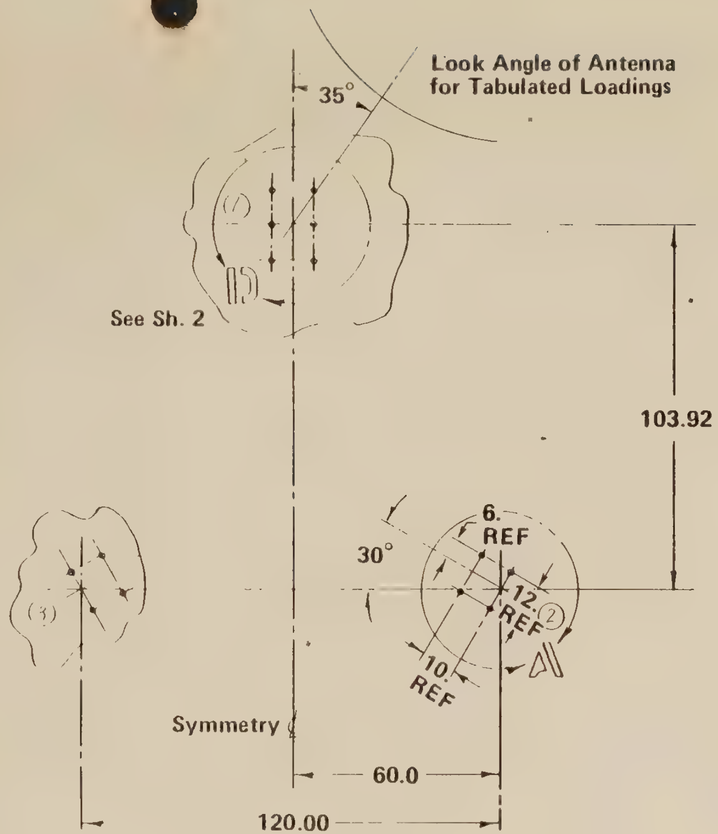
Every Six Months:

1. Check all bolts and fasteners, making sure they are all in place and not loose.
2. Check the foundation and mount for structural failure and repair any damaged parts.
3. Lubricate all points requiring said action per the S-A Instruction Manual.
4. Check for and eliminate corrosion.

Paint:

Each Installation/Instruction manual contains information concerning cleaning and types of paint to be used for touch-up on the various parts of the antenna system. Special attention should be paid to this information in reference to the reflector assembly as it is coated with a special Hi-Reflectance paint.

ATTACHMENT A

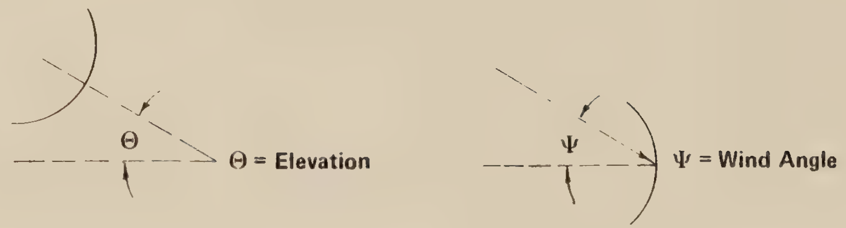



**IMPORTANT NOTICE:**
Since soil conditions, building codes, and other factors vary among various localities, those installing antenna mounts are cautioned to secure professional engineering services for the design and construction supervision of antenna mount foundations.

This antenna mount stud orientation and worst case loading table is furnished to be used to establish required dimensions and location of studs relative to each other and as a guide as to antenna mount characteristics that must be considered in the professional design of a foundation.

Scientific-Atlanta, Inc., does not represent or warrant that any particular design or size of foundation is appropriate for any particular locality or installation.

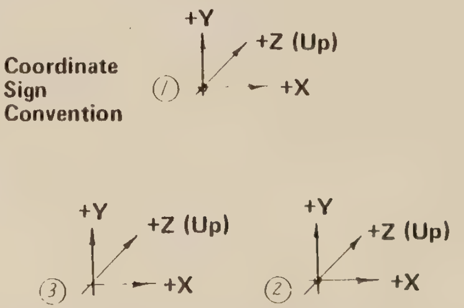
Scientific-Atlanta




Worst Case Loads into Foundation (Pounds) 125 mph, 0°F

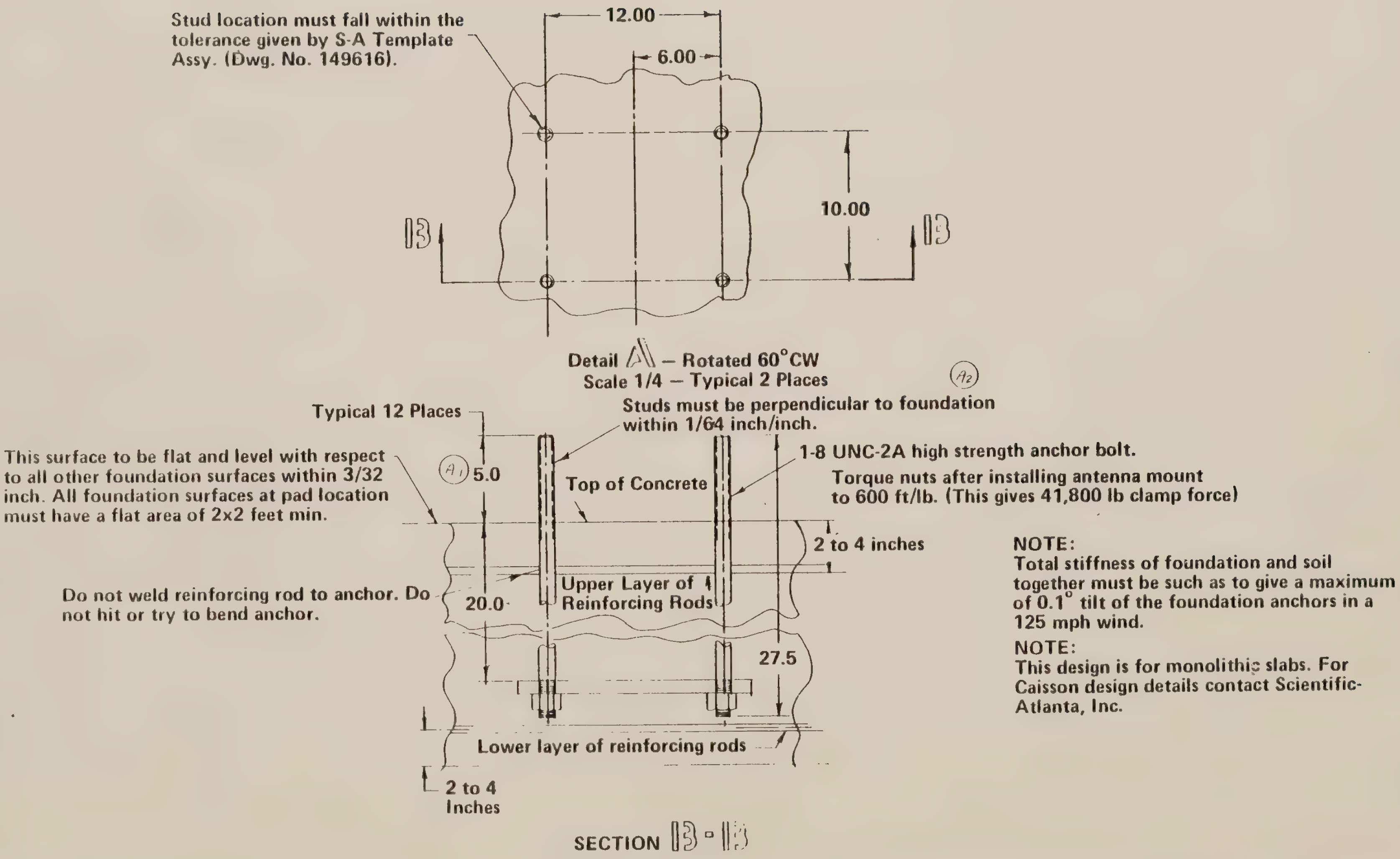
| Loading Conditions | X Component | | | Y Component | | | Z Component | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pad 1 | Pad 2 | Pad 3 | Pad 1 | Pad 2 | Pad 3 | Pad 1 | Pad 2 | Pad 3 |
| Θ=20°;Ψ=140° | 7,897 | 7,926 | -6,547 | 11,321 | -14,164 | 24,543 | -34,093 | -21,791 | 59,816 |
| Θ=20°;Ψ=220° | -17,303 | -1,495 | 9,521 | 3,195 | 3,963 | 14,542 | -52,995 | 11,565 | 45,362 |
| Θ=90°;Ψ=180° | -1,551 | 1,061 | 490 | -5,842 | -1,682 | 6,446 | -29,719 | -1,686 | 17,346 |
| Θ=0°;Ψ=0° | 7,327 | -5,010 | -2,317 | -24,549 | 7,946 | -30,447 | 70,957 | 7,966 | -81,932 |
| Θ=0°;Ψ=180° | -5,584 | 3,819 | 1,766 | 15,436 | -6,057 | 23,207 | -51,338 | -6,072 | 62,451 |

Coordinate Sign Convention



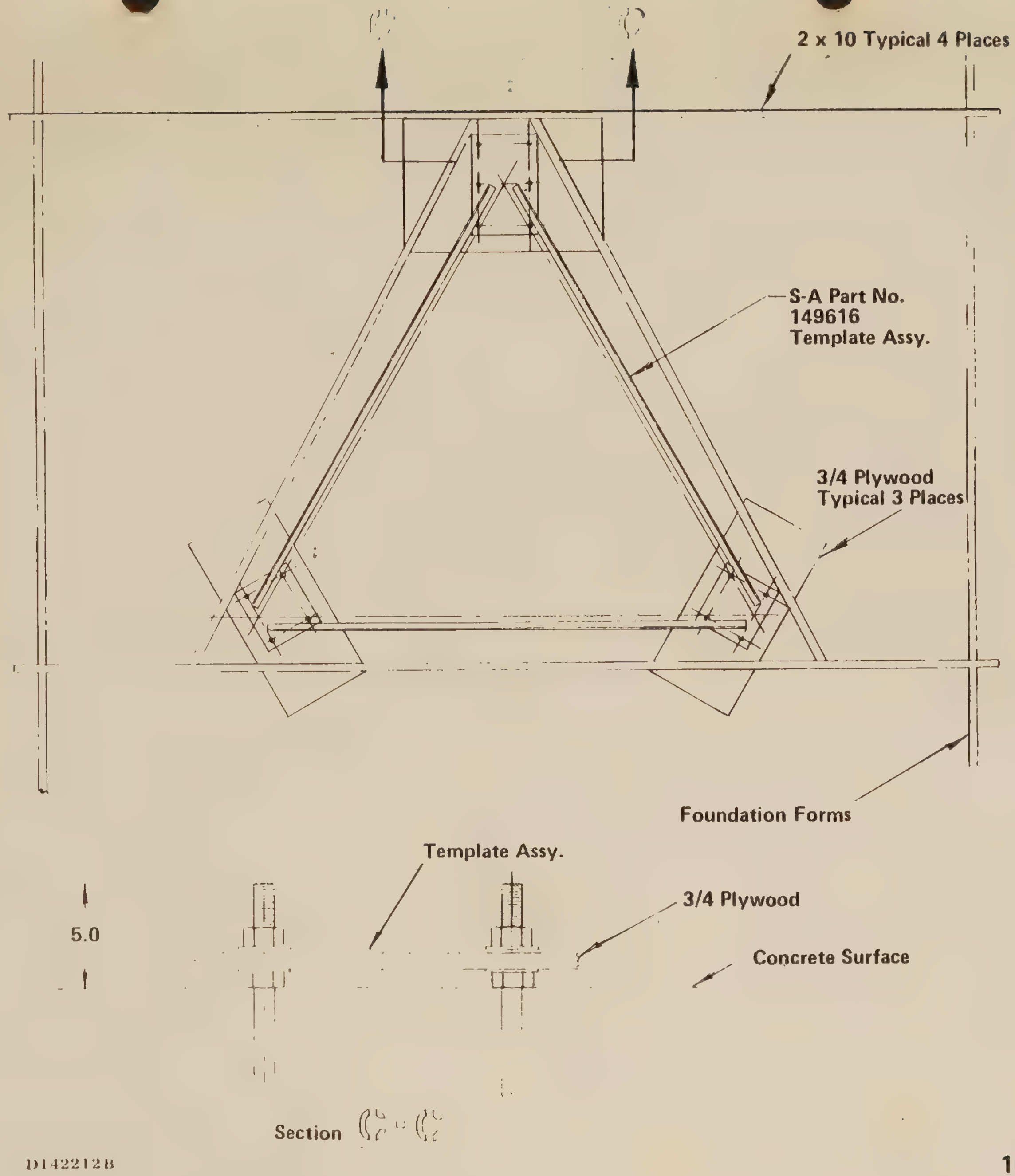

D142212

10 Meter Antenna Mount - Stud Orientation and Worst Case Loading Table (sheet 1 of 3)




D142212

10 Meter Antenna Mount - Stud Orientation and Worst Case Loading Table (sheet 2 of 3)



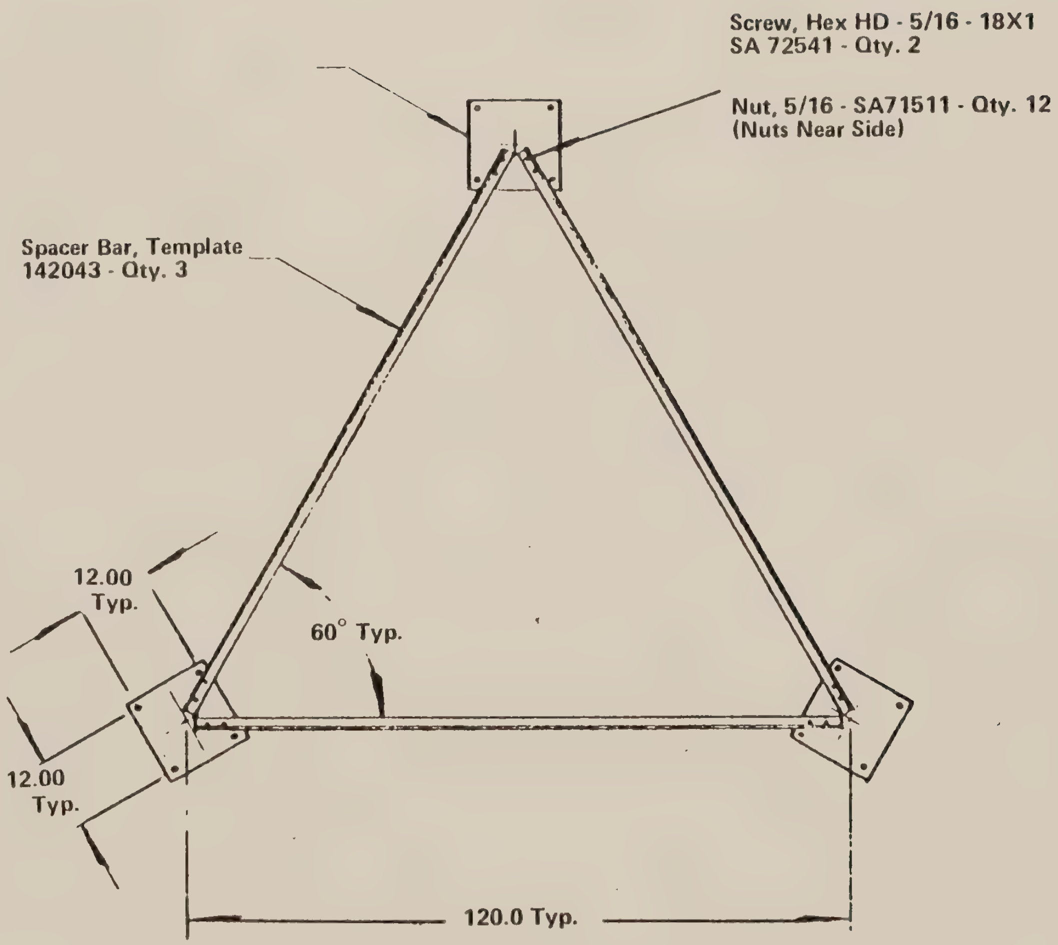

PROCEDURE:

A. Build wooden fixture.
B. Assemble S-A Template Assy. 149616.
C. Place template assy. on wood fixture and pencil in (14) 1 inch holes.
D. Remove template assy. locate centers of 1 inch holes. Drill 1-1/8 holes thru 3/4 plywood.
E. Run 1-8 nut down 5.0 inches on stud. Grease bottom of nut and threads of stud.
F. Put template assy. back down on top of plywood fixture.
G. Put flat washer on stud and run stud up thru plywood and template assy. Put on flat washer and top nut.
H. After all (14) studs are attached thru fixture and template assy. tighten nuts down to hold studs firmly in place.
J. Pour and tamp concrete to level shown on drawing.

NOTES:

1. Do not weld reinforcing bars to studs. If reinforcing bars are interfering with stud location, bend reinforcing bars away. Studs must be vertical and not touching reinforcing bars.
2. Do not hammer or attempt to bend, straighten, or otherwise mishandle anchor studs. These are high strength, low ductility material and will not tolerate any bending.
3. Carefully handle foundation anchors during all phases of foundation work. Do not drop or allow threads to bang against any hard object.

10 Meter Antenna Mount — Stud Orientation and Worst Case Loading Table (sheet 3 of 3)




10 Meter Template Assembly

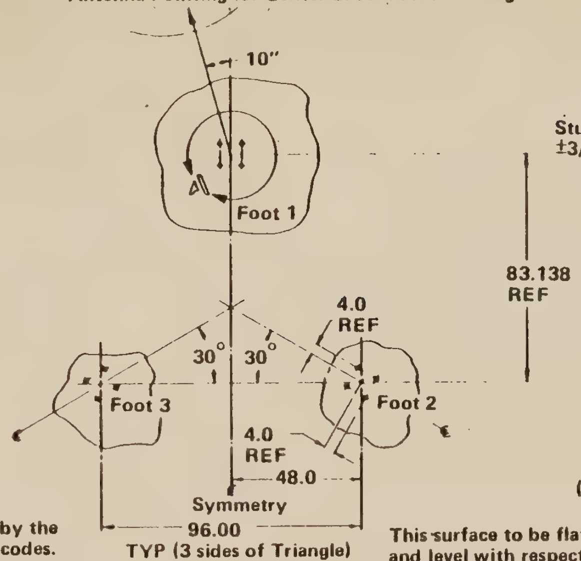
IMPORTANT NOTICE:
Since soil conditions, building codes and other factors vary among various localities, those installing antenna mounts are cautioned to secure professional engineering services for the design and construction supervision of antenna mount foundations.

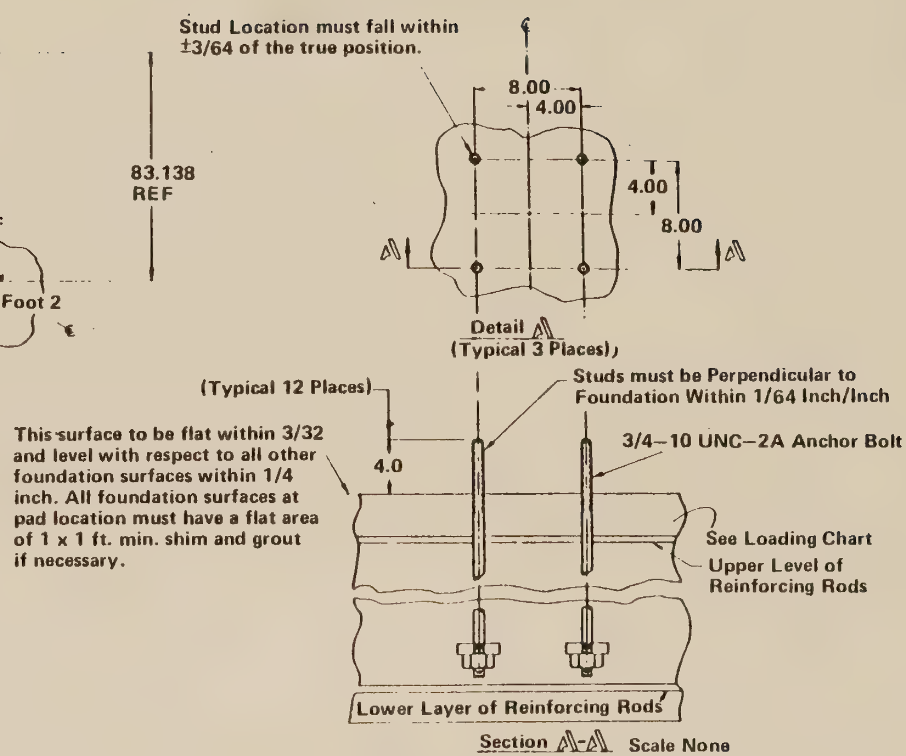
This antenna mount stud orientation and worst cast loading table is furnished to be used to establish required dimensions and location of studs relative to each other and as a guide to antenna mount characteristics that must be considered in the professional design of a foundation.

Scientific-Atlanta, Inc., does not represent or warrant that any particular design or size of foundation is appropriate for any particular locality or installation.

Scientific-Atlanta

NOTES:
1. Proper electrical grounding shall be provided by the installing contractor to meet local applicable codes. This may take the form of a burned grid or a suitable copper stake, depending on local soil conditions. The mount shall be electrically connected to this ground.
2. Provisions must be made to provide suitable support for power, RF and control cables either by buried conduit or overhead raceway. If conduit is supplied it shall be at least 3 inches diameter.
3. Lightning arrestors must be provided across all cables leaving antenna per applicable local codes and N.F.P.A. codes.



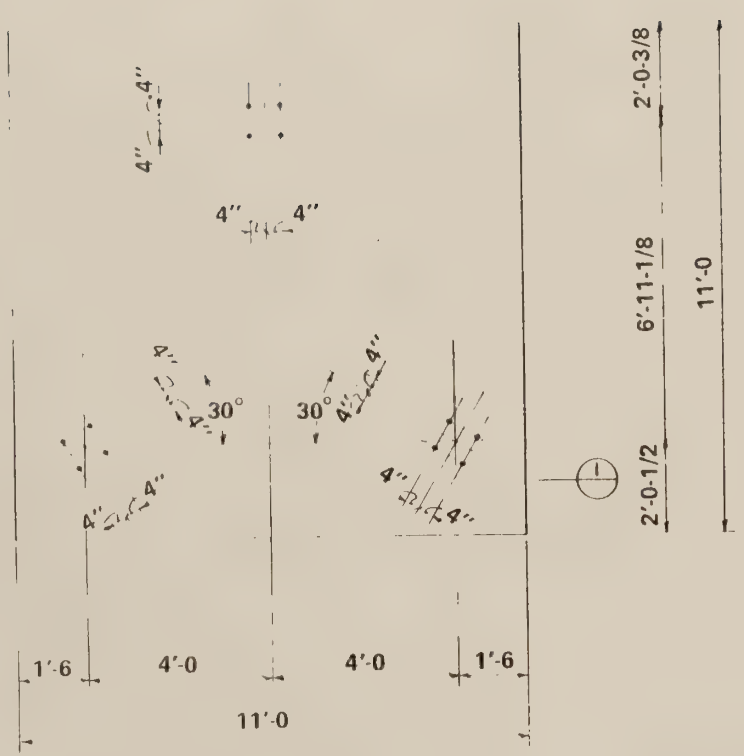

NOTE:
Total stiffness of foundation and soil together must be such as to give a maximum of 0.2" tilt of the foundation anchors in a 125 mph wind.

D155091B

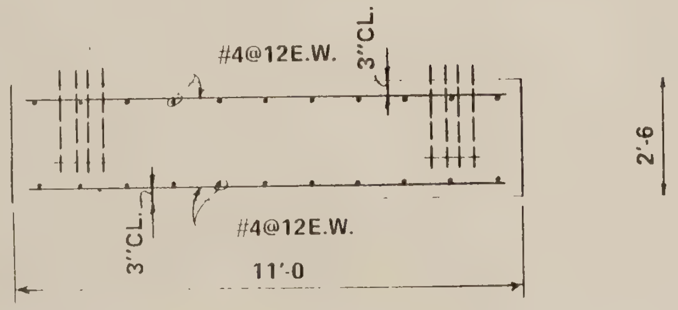
LOADING CHART

Maximum Foundation Loads in Pounds for 125 mph Wind and 1 Inch of Radial Ice on Back of Reflector, Hub, and Truss Members

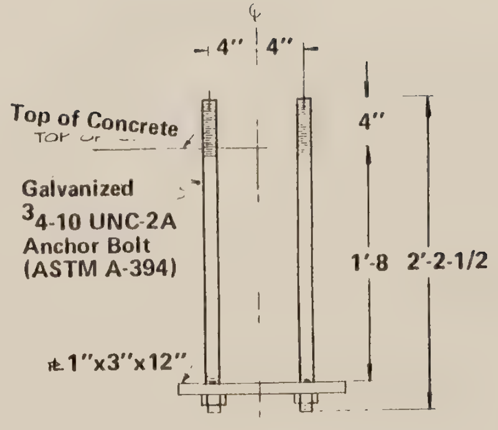
| Foot | Max. Up Load Wind Only | Max. Down Load Wind Only | Down Load Dead Weight | Down Load Ice | Max. Horizontal Load |
|---|---|---|---|---|---|
| 1 | 10,300 | 14,300 | 1,400 | 1,000 | 5,500 |
| 2 | 9,700 | 10,100 | 200 | 0 | 12,200 |
| 3 | 9,700 | 10,100 | 200 | 0 | 12,200 |




Foundation Plan No. 1




Section



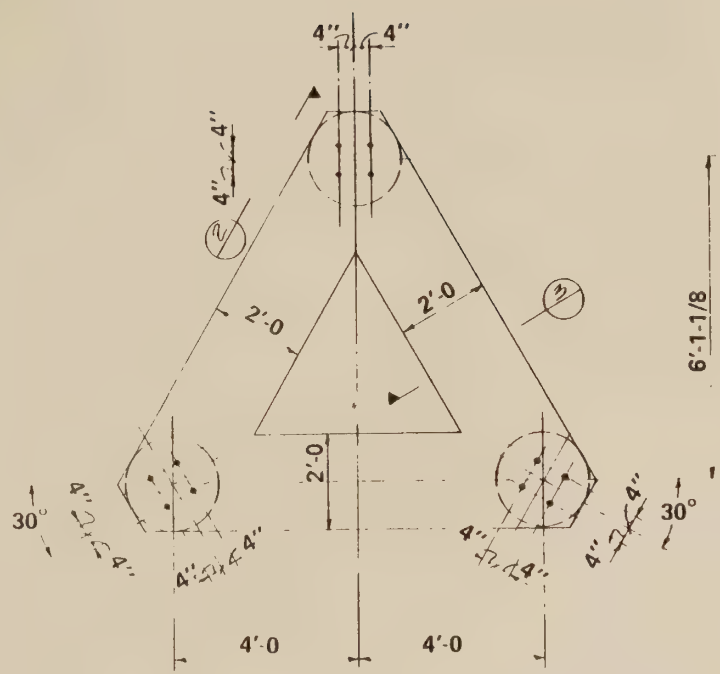

Typical Anchor
Bolt Detail

NOTES:

1. Soil bearing pressure to be minimum of 2000 P.S.F.
2. Concrete to be 3000 P.S.I. compressive strength @28 days.
3. Reinforcing bars to be grade 40.
4. Do not weld anchor bolts.
5. Frost line to be maximum of 2'-6" below finished grade.
6. Footing designed for 125 mph wind.

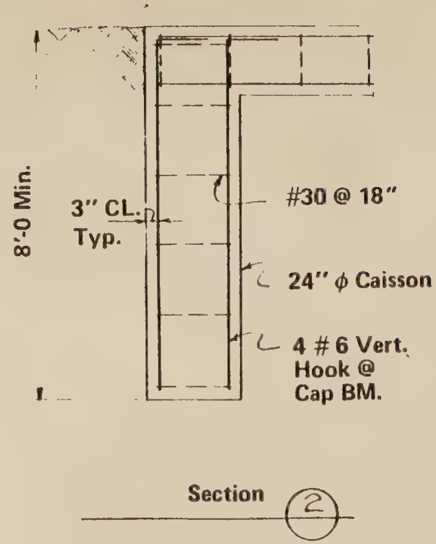
5 Meter Model 8008 Typical Foundation Plan (sheet 1 of 3)

D152874A

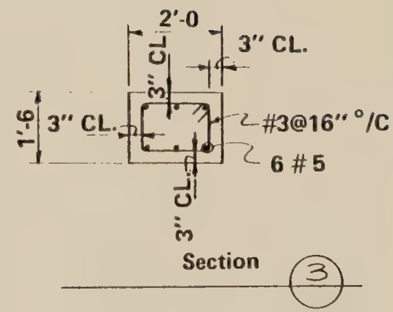



Foundation Plan No. 2

NOTES:
1. Soil bearing pressure to be minimum of 3000 P.S.F.
2. Concrete to be 3000 P.S.I. compressive strength @28 days.
3. Reinforcing bars to be grade 40.
4. Do not weld anchor bolts.
5. Tie beam and caissons to be poured monolithically.
6. Footing designed for 125 mph wind.




Section 2



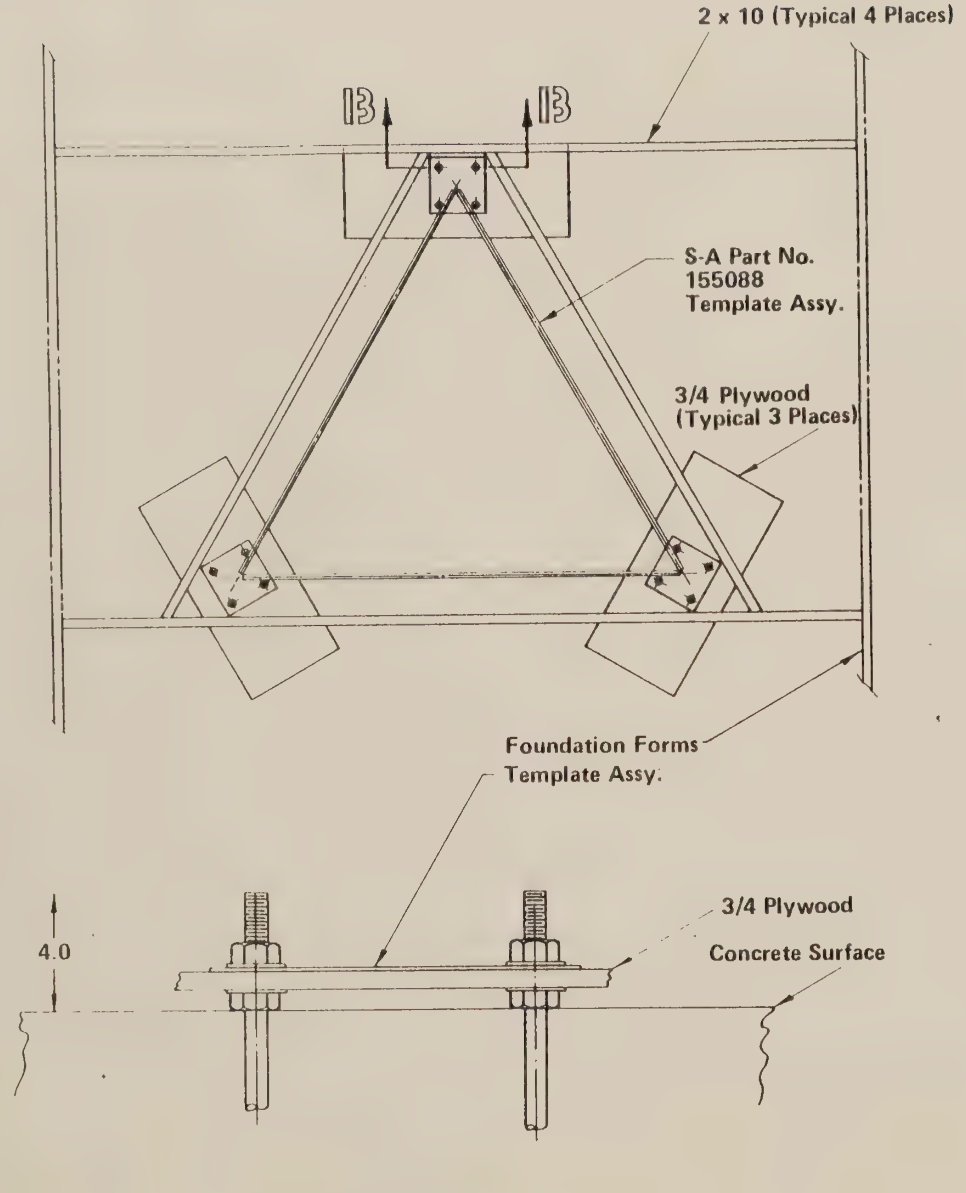

Section 3

IMPORTANT NOTICE:
Scientific-Atlanta does not represent or warrant that any particular design or size of foundation is appropriate for any particular locality or installation.
Scientific-Atlanta

GENERAL NOTES:
1. Proper electrical grounding shall be provided by the installing contractor to meet local applicable codes. This may take the form of a buried grid or a suitable copper stake, depending on local soil conditions. The mount shall be electrically connected to the ground.
2. Provisions must be made to provide suitable support for power, RF and control cables either by buried conduit or overhead raceway. If conduit is supplied it shall be at least 3 inches diameter.
3. Lightning arrestors must be provided across all cables leaving antenna per applicable local codes and and N.F.P.A. codes.

D152874A

5 Meter Model 8008 Typical Foundation Plan (sheet 2 of 3)




Section B-B

PROCEDURE:

A. Build wooden fixture.
B. Assemble S-A Template Assy. 155088.
C. Place template assy. on wood fixture and pencil in (12) 3/4-inch holes.
D. Remove template assy. — locate centers of 1 inch holes — drill 1 inch holes thru 3/4 plywood.
E. Run 3/4 - 10 nut down 4.0 inches on stud. Grease bottom of nut and threads of stud.
F. Put template assy. back down on top of plywood fixture.
G. Put flat washer on stud and run stud up thru plywood and template assy. Put on flat washer and top nut.
H. After all (12) studs are attached thru fixture and template assy, tighten nuts down to hold studs firmly in place.
I. Pour and tamp concrete to required level.
J. Allow concrete to set up.
K. Remove template assy, 3/4 plywood and all nuts.

NOTES:

1. Do not weld reinforcing bars to studs. If reinforcing bars are interfering with stud location, bend reinforcing bars away. Studs must be vertical.
2. Do not hammer or attempt to bend, straighten, or otherwise mishandle anchor studs.
3. Carefully handle foundation anchors during all phases of foundation work. Do not drop or allow threads to bang against any hard object.

D152874B

5 Meter Model 8008 Typical Foundation Plan (sheet 3 of 3)

# INSTALLATION CONSIDERATIONS FOR TRANSMIT EARTH STATIONS

Thomas M. Williams
Senior Engineer
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

## INSTALLATION CONSIDERATIONS FOR TRANSMIT EARTH STATIONS

The installation of a transmit earth station is similar to the installation of a receive-only earth station in many respects. Items such as foundation centerline, antenna motion clearance, low noise amplifier subsystems, air-dielectric cable, power drives, and video receivers are installed and operated in the same manner in both transmit and receive-only earth stations.

Other items must be considered, however, which are not common to typical receive-only stations. The purpose of this paper is to discuss some of the installation details of these items.

### AC Power

The ac power requirements of transmit earth stations are considerably greater than for receive-only stations. Typical ac requirements for a receive-only station include video receivers, low noise amplifiers, compressor-dehydrator, and possibly motor drive control. The total power required to operate this equipment is less than 10 kW.

The total ac power required to operate a receive-only earth station is exceeded by the operation of one 3 kW HPA. Each HPA requires 12 kW of three phase ac power. Since the typical transmit station is configured for automatic protection with a hot standby HPA, the total power required for a transmit earth station approaches 50 kW with motor driven antenna and feed/subreflector deicing.

Other items may raise this total to even higher values. Additional uplinks add about 13 kW each including power required for the HPA, video exciter, and additional switching equipment.

If main reflector deicing is added, the total power required almost doubles. Half reflector deicing requires 24 kW of power. Full reflector deicing requires 48 kW. In areas where severe icing does not occur feed/subreflector deicing may be used alone. Its power consumption is only about 5 kW.

### Waveguide

The RF output of the HPA switching system must be connected to the 6 GHz flange of the antenna feed system with waveguide to minimize power loss between the HPA and antenna. Typically this is accomplished with elliptical waveguide which is a semiflexible permanent waveguide that does not require an exact layout for installation.

To install this waveguide, a cable tray must be constructed out of heavy cable with a cover for protection from ice and any objects which might fall and damage the waveguide run. Waveguide runs and their cable trays are generally kept short to minimize power loss. Every effort should be made to keep the total waveguide length less than a hundred feet long.

The last piece of waveguide installed between the semiflexible run and the antenna feed is a six-foot length of flexible-twistable waveguide. This is installed to allow antenna motion without waveguide and cable tray damage.

### Cooling

Air conditioning requirements should be tailored to the size of the earth station and the particular configuration at the site. Each unit of GCE generates about 100 watts of heat which must be cooled or exhausted from the building.

The largest single source of heat in a transmit station, however, is the HPA's and associated equipment. Each HPA is vented through the rear wall of the equipment shelter. Two 4-inch diameter vents are provided. One is for fresh air, the other to exhaust the heated air from the equipment shelter. Each HPA has two blowers to accomplish this task. Approximately 8 kilowatts of heat are removed from each HPA in this manner.

If the shelter has been properly vented as described in the preceding paragraph, only about one kilowatt of heat per HPA will remain in the shelter to be cooled by the air conditioning system.

As a safety precaution, the shelter should also contain a fresh air system to circulate outside air into and out of the shelter in the event that the air conditioning system fails. This system can be fully automatic with a temperature switch to activate the blower.

**Shelter Requirements** The equipment space required for a transmit earth station is considerably greater than for a receive-only station. For the typical earth station with redundant up/down links and options such as motorized antenna positioning and deicing, two standard 19-inch racks are required to accommodate the GCE and control electronics. Each HPA will require rack space that is approximately 28W x 32D x 78H inches. In addition, space for waveguide runs and switching must be provided in the shelter.

These facts dictate that the minimum shelter size for a redundant transmit/receive earth station is about 10 feet by 18 feet. Smaller sizes may be used, but they are quite cramped, especially when testing and maintenance on the earth station is in progress.

**Safety** Since video transmit earth stations frequently have EIRP's in excess of 80 dBW, a microwave radiation hazard exists in the area directly in front of the main reflector. Fortunately, the beam width of the 10 meter antenna is extremely narrow and most of the microwave power is confined to the area within an imaginary clinder radiating from the front sides of the main reflector. Most U.S. locations have fairly high elevation look angles to the domestic satellites, therefore little or no real hazard exists in most locations.

However, the area directly in front of the main beam should not be blocked by any object. There are several reasons for this: safety, earth station performance (G/T), cross-polarization rejection, and others.

It is wise to have the areas surrounding the antenna and mount completely enclosed within a fence. This is for the protection of the antenna from vandals and for the protection of people (mostly children) who like to climb. Injuries may occur from falling from the mount or from radiation hazard. Climbing on the main reflector when the station is transmitting is extremely hazardous as the area between the subreflector and the main reflector has a very high microwave radiation density.

# PERFORMANCE VERIFICATION VIDEO UPLINK

Thomas M. Williams
Senior Engineer
Satellite Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Performance Verification Video Uplink**

### Output Power

1. *Connect the test equipment as shown in Figure 1.*
2. *Check exciter frequency for mid HPA channel.*
3. *Set 461 Exciter for -10 dBm output.*
4. *Adjust HPA input attenuator for maximum output.*
5. *HPA output power may be calculated from output power meter reading by adding coupler valve plus any attenuation between coupler and power meter.*

*Specification >34.4 dBw*

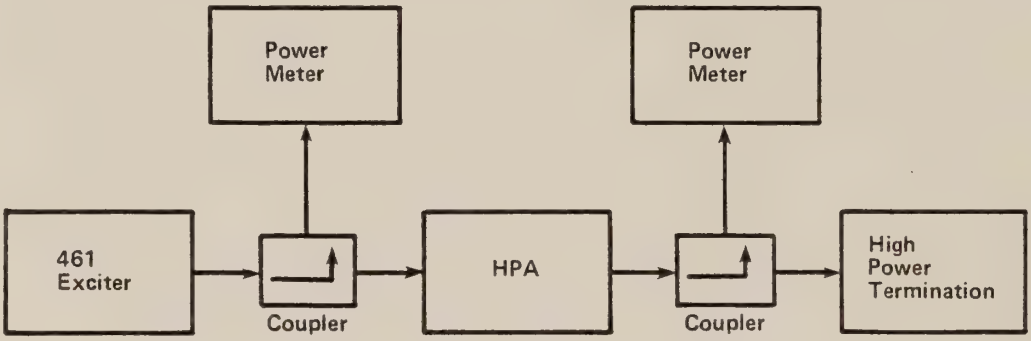



Figure 1. Output Power — HPA Gain.

### EIRP

*EIRP may be calculated by measuring the output power at the OMT flange and adding the known antenna gain.*

*If the waveguide and switching system losses are known, then:*

$$EIRP = G_{Antenna} + P_{HPA} - L_{WG} - L_{SW}$$

### HPA Gain

1. *Connect the test equipment as shown in Figure 1.*
2. *Check exciter frequency for mid HPA channel.*
3. *Set input HPA input attenuator for nominal output power.*
4. *HPA gain is HPA Output Power (dBw) Exciter Output Power (dBw)*

*Specification >70 dB*

### IF-RF Gain and Gain Flatness

1. *Connect the equipment as shown in Figure 2.*
2. *Adjust the sweep oscillator for 70 MHz ±20 MHz.*
3. *Check the exciter output for correct HPA channel output.*
4. *Calibrate scope output level and gain using attenuation and known input.*
5. *Measure IF-RF Gain and Gain Flatness directly from scope display.*

*Specification: Total of .5 dB in center third of BW.*
*Total of 1 dB over remaining two-thirds of BW.*

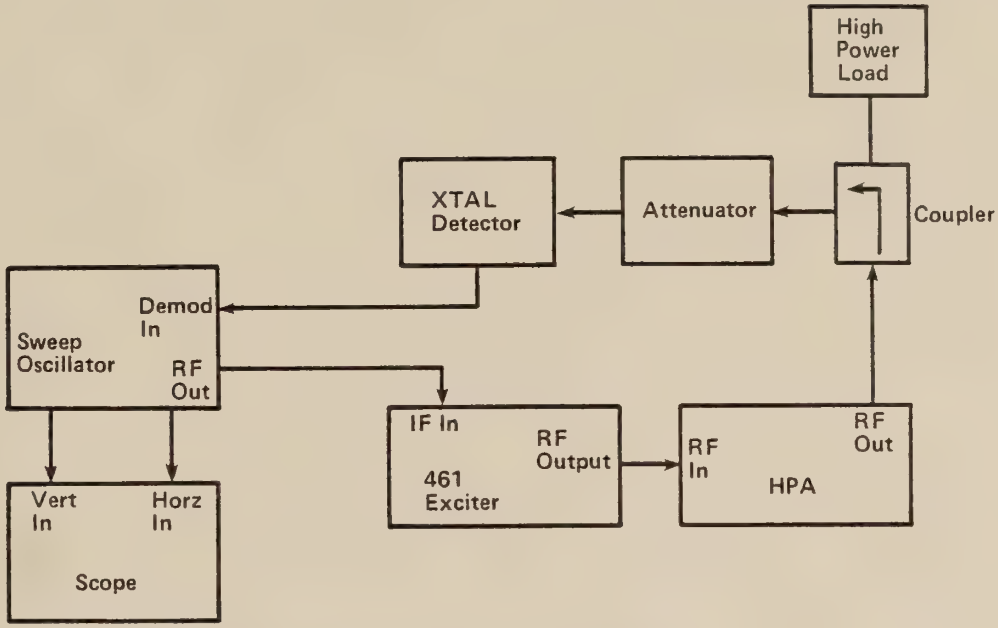



Figure 2. IF - RF Gain — Gain Flatness.

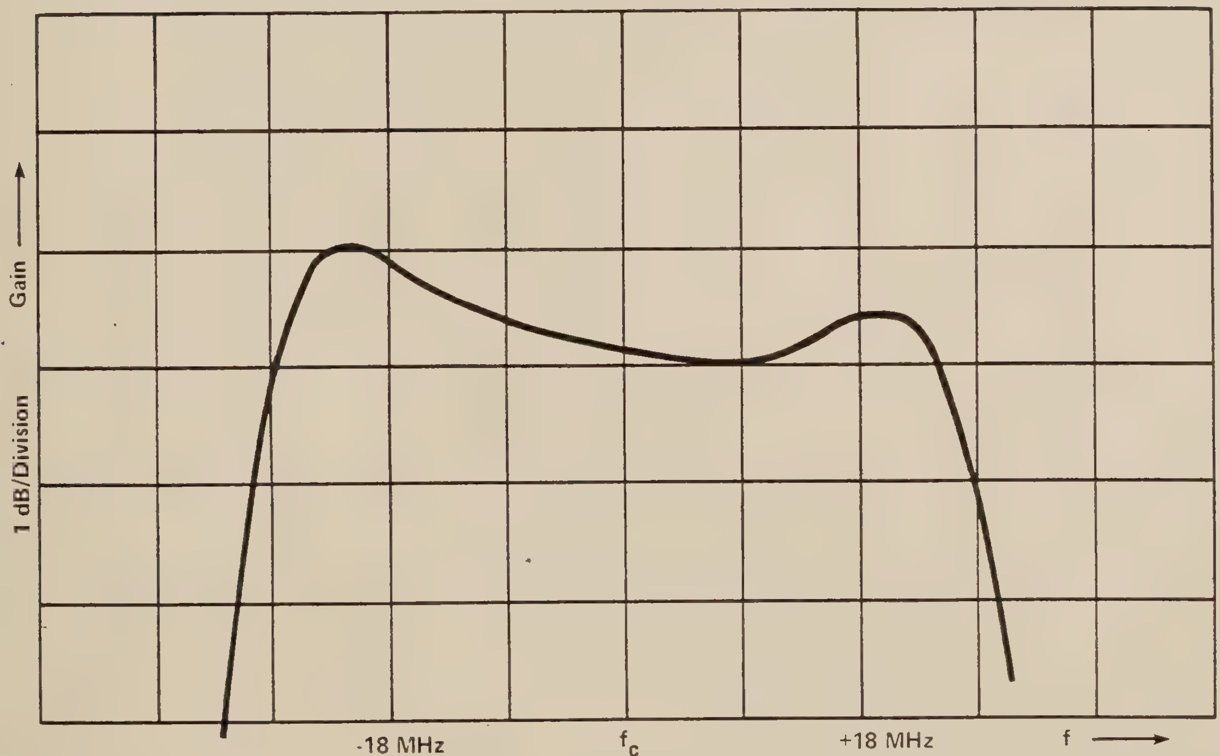



Figure 3. Typical HPA Channel.

## Group Delay

1. *Connect test equipment as shown in Figure 4.*
2. *Check the exciter frequency for correct HPA channel.*
3. *Calibrate the MLA for 1nsec/cm group delay reading.*
4. *Measure the group delay across the channel.*

*Specification: Linear — 0.25 ns/MHz*
*Parabolic — 0.05 nsec/MHz*
*Ripple — 2 nsec/p-p*

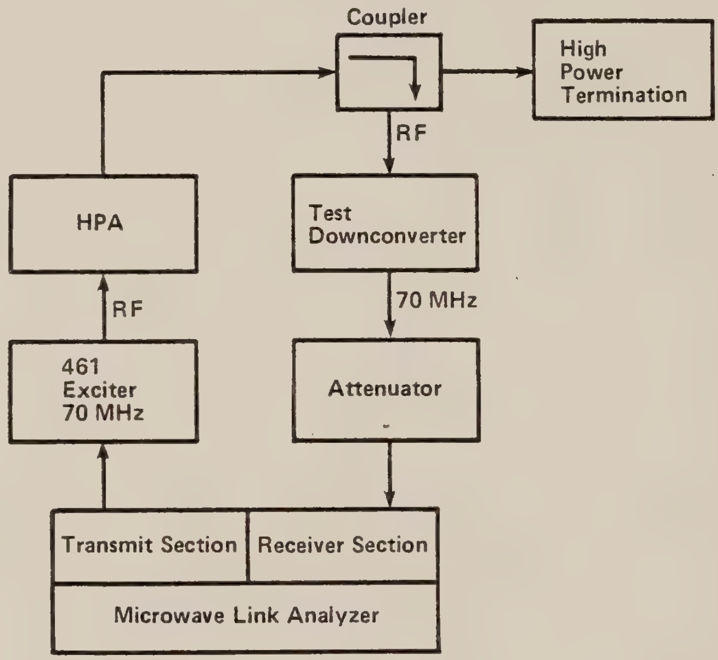



Figure 4. Group Delay.

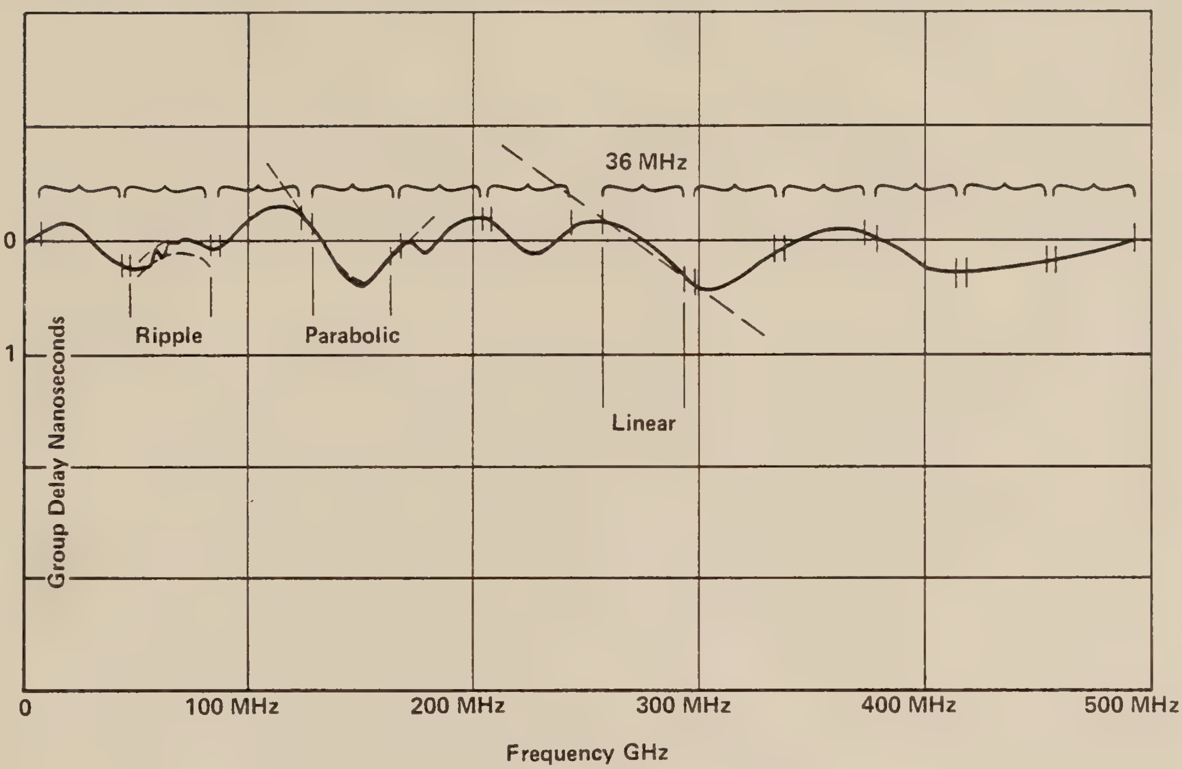



Figure 5. Typical Group Delay Measurement

Intermod

1. *Connect the test equipment as shown in Figure 6.*
2. *The 461 Exciter is driven by two in-band signals spaced such that the 3rd order intermod products are shown on the spectrum analysis.*
3. *Measure the intermod performance per the graph shown in Figure 7.*

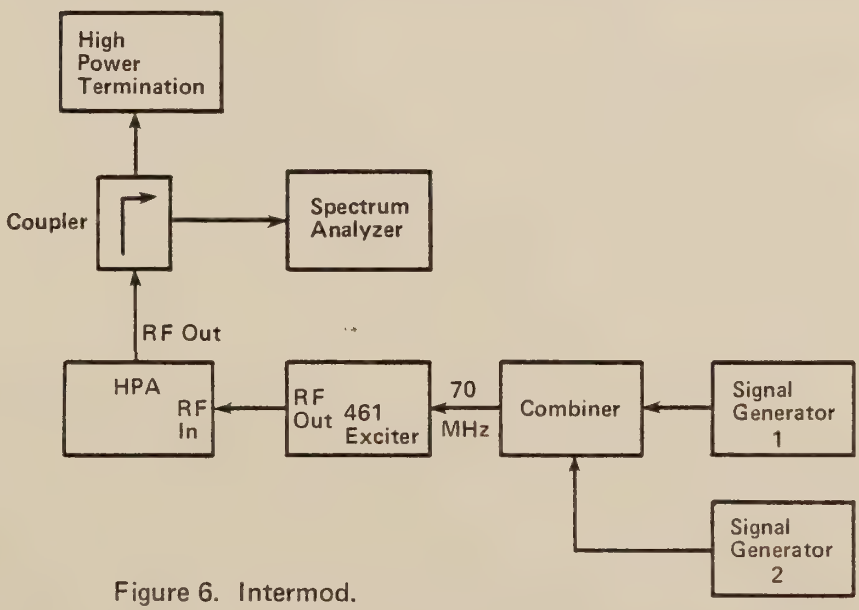



Figure 6. Intermod.

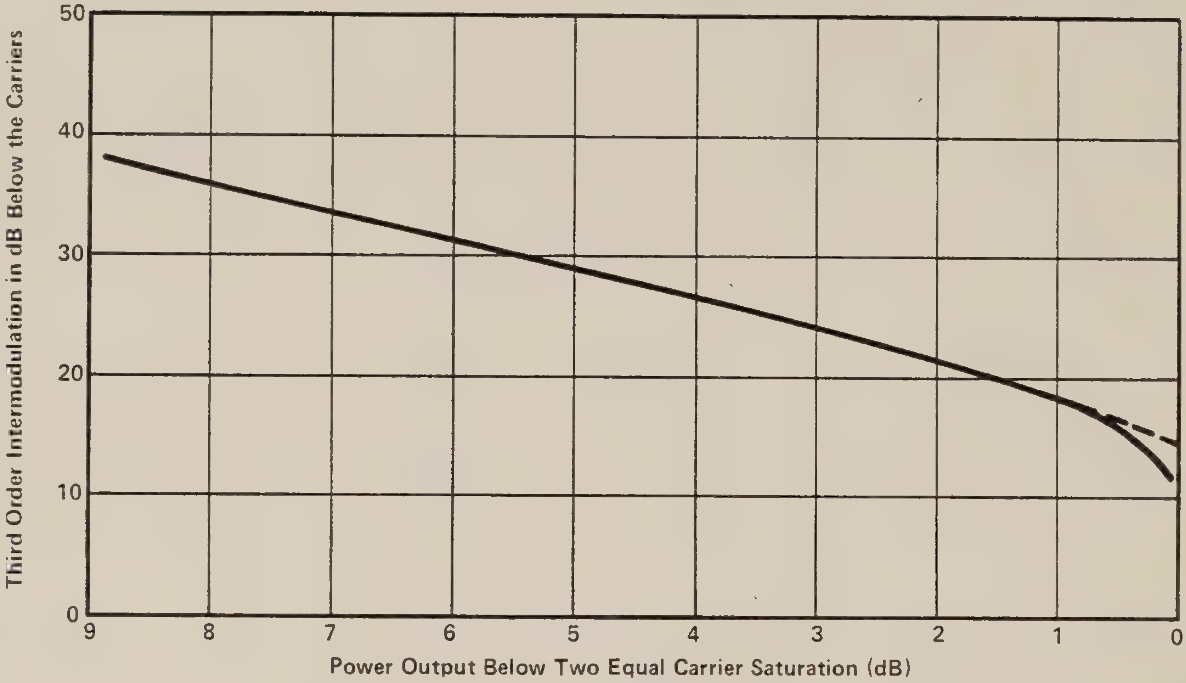



**Figure 7. Third Order Intermodulation Distortion Under Two Equal Carrier Conditions.**

Video Tests

1. *Connect test equipment as shown in Figure 8.*
2. *With all equipment set up for 1V p-p levels, measure baseband flatness using baseband signal generator and RMS voltmeter or calibrated display.*
3. *Using video signal generator and waveform monitor with vector scope measure all video parameters.*

*Typical measurements are:*

*Differential Phase $< \pm 0.5°$*
*Differential Gain $< \pm 2\%$*
*Field Time Distortion $< 1.0\%$*
*Short Time Distortion $< 0.5\%$*
*Chrominance to Luminance Delay $< 30$ ns*
*Non-Linear Distortion $< 3\%$*

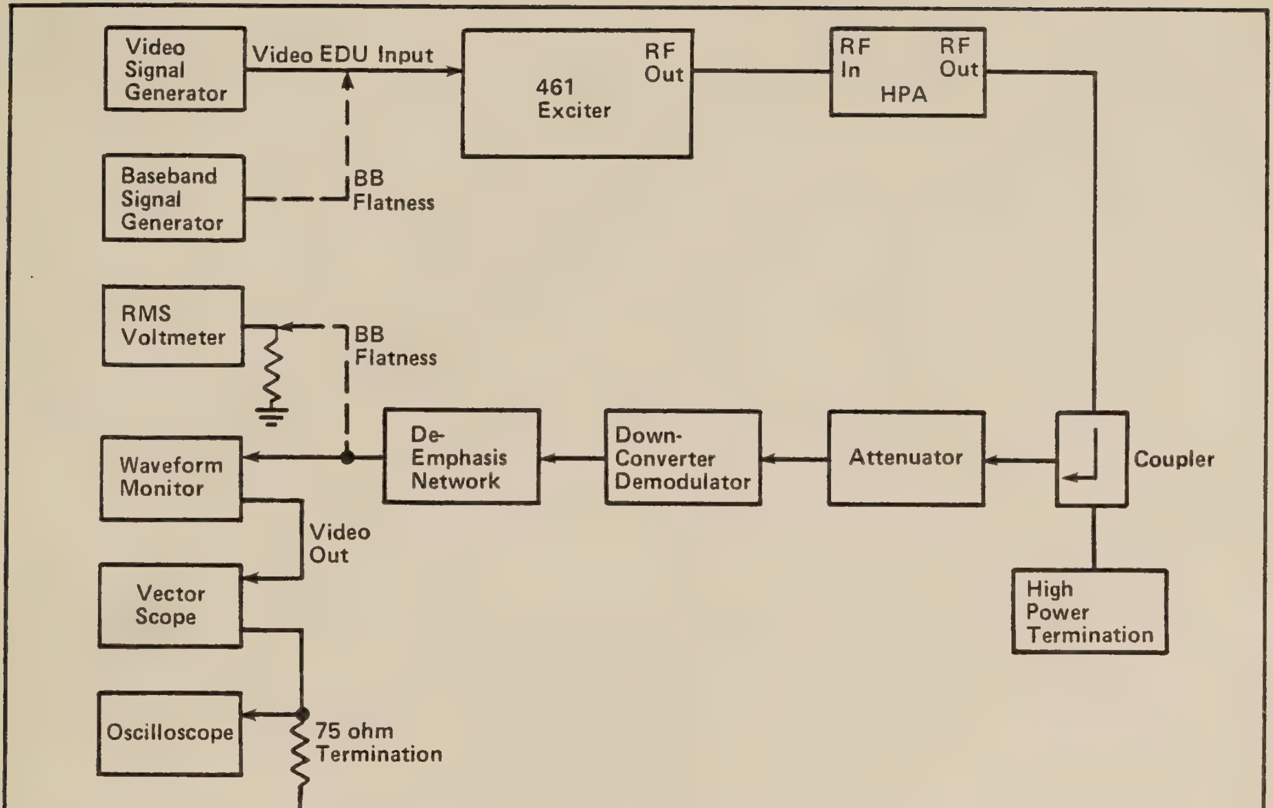



Figure 8. Video Test Set-Up.

# PERFORMANCE VERIFICATION

Larry C. Lawson
Engineer
Cable Communications Division

EARTH STATION SYMPOSIUM '78

Scientific-Atlanta, Inc.
Atlanta, Georgia

November 8 - 10, 1978

**Abstract** The proof of performance of a typical satellite video receive station consists of a series of RF and video tests which are compared to the specified parameters. The proof of performance test records provide a valuable guideline for routine maintenance and troubleshooting. Troubleshooting a satellite video receive station requires a basic understanding of the operation of the system components, receiver, LNA, etc. and how the component parameters affect the system performance. This paper discusses the performance evaluation tests, troubleshooting, and maintenance.

## PERFORMANCE VERIFICATION

### Introduction

Once the antenna is assembled, the LNA and cable installed, the system turned on, and the satellite located, the system engineer is faced with the task of determining that the system is operating properly; in other words evaluating the performance of the station. This evaluation can be as simple as looking at the receiver output on a TV monitor or as complex as available test equipment will alow.

The procedures which follow describe the tests currently performed by Scientific-Atlanta field personnel to evaluate the performance of a satellite video receive station.

### Test Waveforms

All waveform measurement techniques described in this paper are based on the IRE scale units of measurement (see Figure 1). The waveform technology used throughout this paper is in accordance with the definitions shown in Figure 2 wherein the standard composite color video signal is defined.

The two principal test signals that are required to conduct the various measurements described in this report are:

1. The composite test signal shown in Figure 3, which consists of a line bar, a 2T pulse, a modulated 12.5T pulse, and a 5 riser modulated staircase signal.
2. The combination test signal shown in Figure 4, which consists of a white flag, a multiburst, and a 3 level chrominance signal.

It should be noted that except where full field test signals are essential to the measurement of a particular parameter, the measuring technique for each parameter is the same for both vertical interval test signals (VITS) and full-field test signals. Furthermore, the performance objectives apply irrespective of the average picture level (APL) within the APL range of 10% to 90%. This is an important point to remember when making VITS measurements, particularly during program transmission periods where control cannot be exercised over the APL value of picture signal. Many of the parameters can be markedly affected by APL variations and accordingly the operator should allow sufficient time when making VITS measurements to ensure a good portion of the APL range is explored by the picture signal.

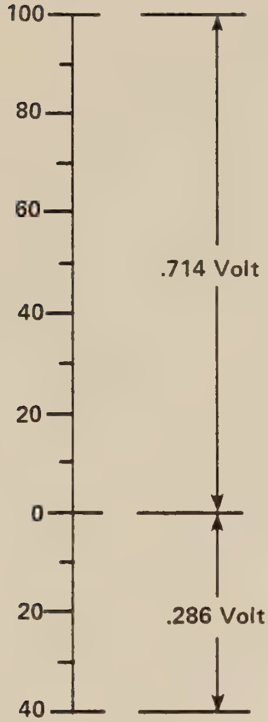



Figure 1. The IRE Scale Units

Waveform Terminology

| | |
|---|---|
| A | — The peak-to-peak amplitude of the composite color video signal |
| B | — The difference between block level and blanking level (set-up) |
| C | — The peak-to-peak amplitude of the color burst |
| L | — Luminance signal - nominal value |
| M | — Monochrome video signal peak-to-peak amplitude (M=L+S) |
| S | — Synchronizing signal - amplitude |
| $T_b$ | — Duration of breezeway |
| $T_{si}$ | — Duration of line blanking period |
| $T_{sy}$ | — Duration of line synchronizing pulse |
| $T_u$ | — Duration of active line period |

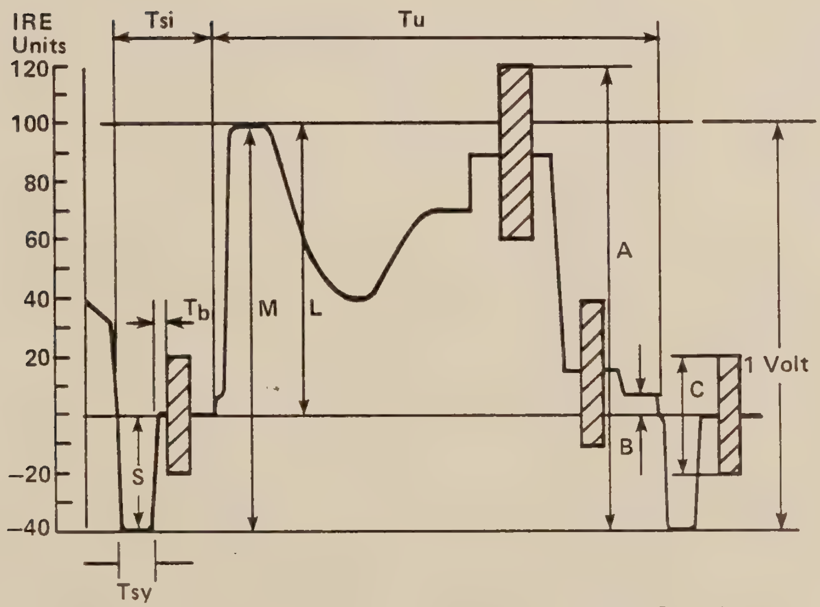



Figure 2. The Standard Composite Color Video Signal

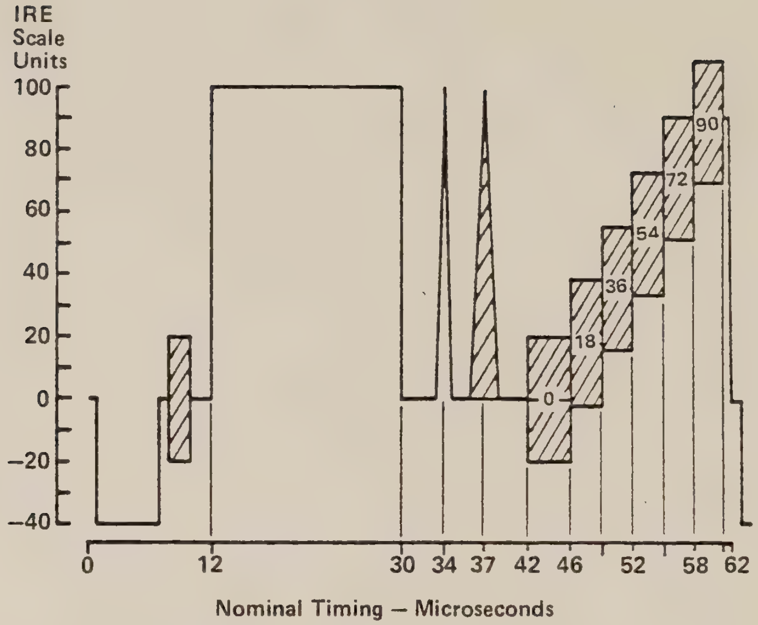
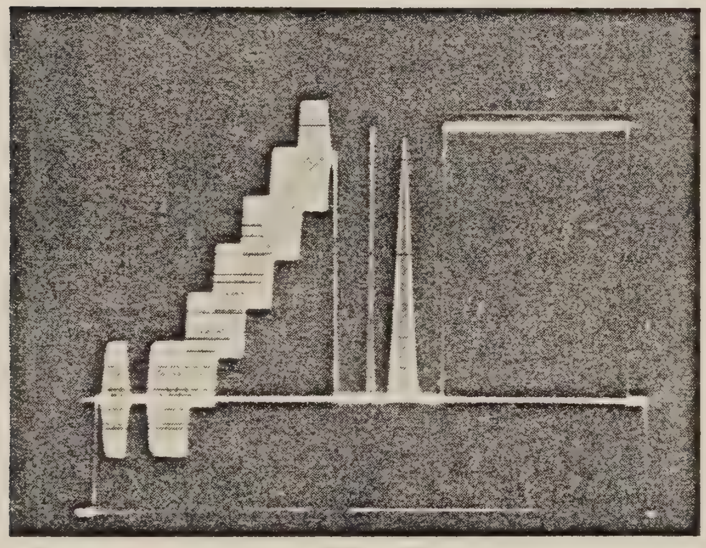



Figure 3. The Composite Test Signal



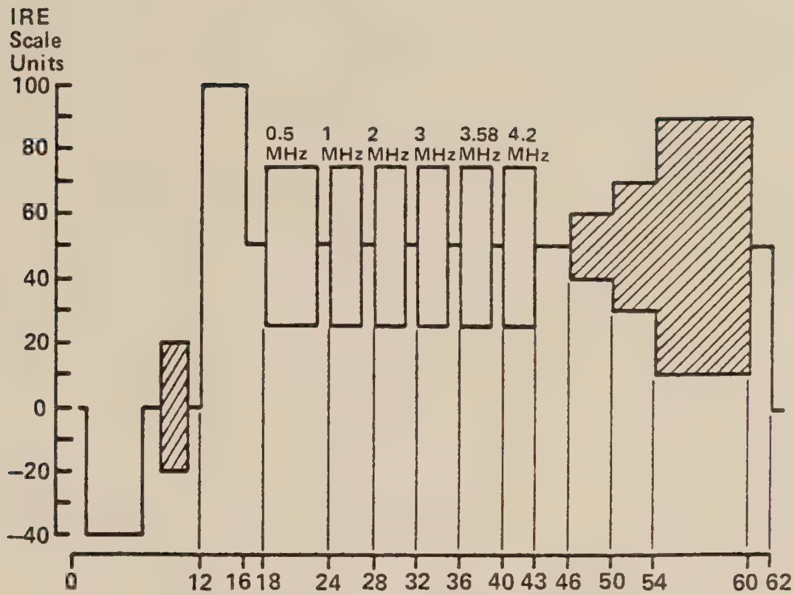
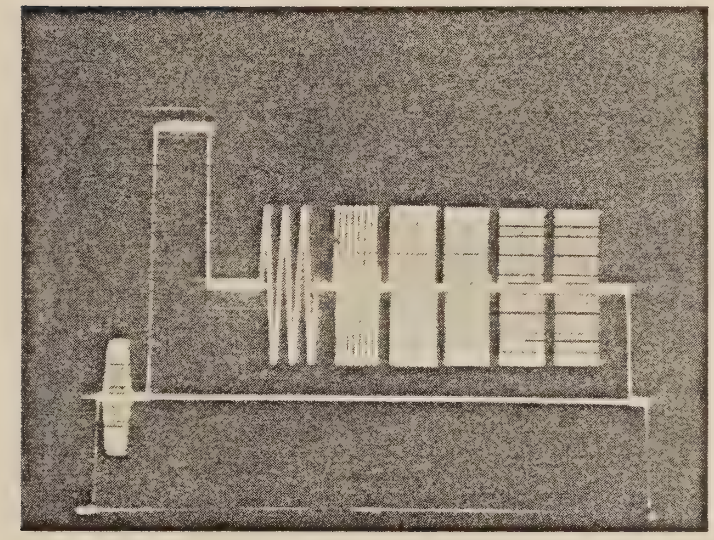



Figure 4. The Combination Test Signal



**Test Equipment Required**

Tektronix 520A Vector Scope, or equivalent
Tektronix 1480 Waveform Monitor, or equivalent
Tektronix 147A NTSC Signal Generator, or equivalent
Tektronix CCIR Random Noise Low Pass Filter, or equivalent
Hewlett-Packard 435A RMS Power Meter, or equivalent
Hewlett-Packard 8558 Spectrum Analyzer, or equivalent
Hewlett-Packard 334A Audio Distortion Analyzer, or equivalent

**Tests Performed**

Main IF Carrier-to-Noise Ratio
CCIR Weighted Signal-to-Noise Ratio
Reduced Amplitude Video Response
"K" Factor ($K_{2T}$)
Luminance-Chrominance Delay
Differential Gain
Differential Phase
Audio Test Tone Signal-to-Noise Ratio
Audio Test Tone Distortion

**Test Procedures**

1. Main IF Carrier-to-Noise Ratio

This test verifies the performance of the RF and IF portions of the system, this is apparent from the expression for C/N:

$$C/N = (EIRP - LP + G/T - D) - 10 \log B\ IF$$

Where

EIRP = Satellite effective isotropic radiated power in dBW

Lp = Path loss (free space) in dB

K = Boltzmann's constant = −168.6 dBW/MHz/°K

$B_{IF}$ = Effective IF Noise Bandwidth in MHz

G/T = System figure of merit in dB/°K = Ga − 10 log ts

Ga = Antenna gain in dB

ts = system noise temperature in °K

ts = ta + tl + tc/gl + tr/(glxgc)

ta = Antenna noise temperature in °K

tl = LNA noise temperature in °K

tc = Cable noise temperature in °K

tr = Receiver noise temperature in °K

gc = Cable gain ratio

gl = LNA gain ratio

Examining the parameters which affect C/N it becomes obvious that this is perhaps the one most important measurement to be considered. The C/N ratio is measured as follows:

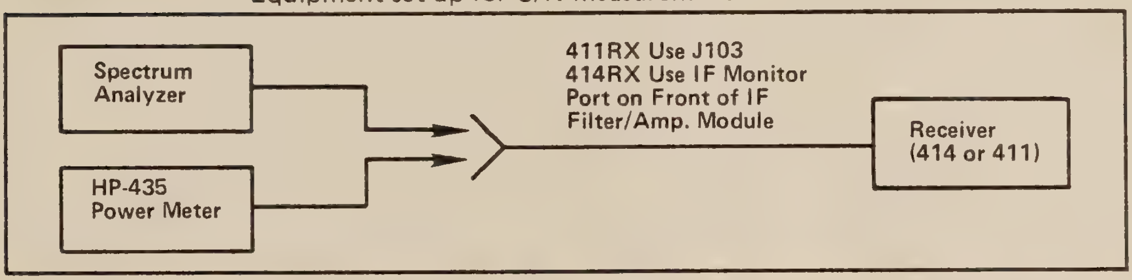
A. Set the receiver AGC/MGC switch to MGC position.
B. Connect spectrum analyzer to filtered 70 MHz IF monitor port.
C. Raise antenna elevation until there is no input signal to the receiver as shown by the spectrum analyzer.
D. Connect the HP435 power meter to the 70 MHz filtered monitor port. Measure the noise power at this port and record it.
E. Lower the antenna elevation until an absolute peak is reached as shown on the power meter, and record this reading as carrier plus noise power.
F. (Carrier + Noise Power) — (Noise Power) = Carrier + Noise-to-Noise Ratio = C+N/N
G. Compute carrier-to-noise ratio (C/N) as follows:

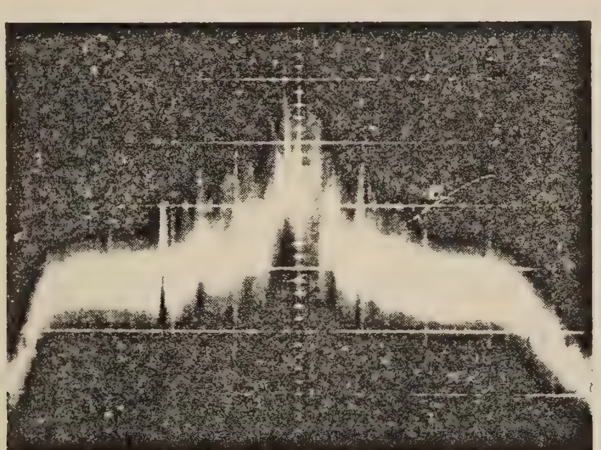
$C+N/N = 16$

$C/N = 10 \log [(\log^{-1} 16) - 1]$

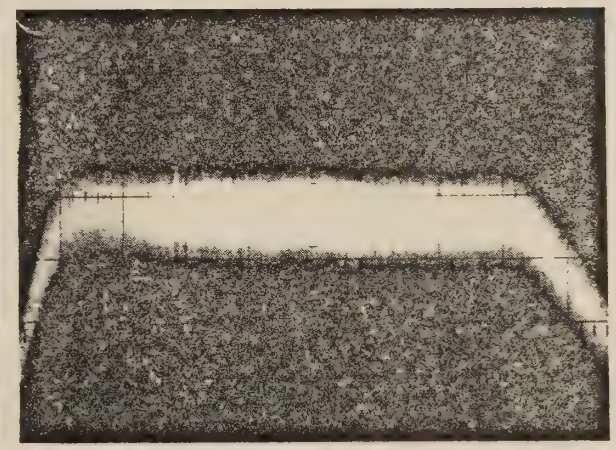
$C/N = 15.89$

Equipment set up for C/N measurement:



Spectrum Analyzer Display
70 MHz Center Frequency
Showing Received FM Signal



Spectrum Analyzer Display
70 MHz Center Frequency
Showing No Received Signal

2. CCIR Weighted Video Signal-to-Noise

This test verifies the performance of the up and down link video equipment and that of the program data 17 VITS - vertical internal test signals are not inserted at the up link. The expression used for CCIR signal-to-noise (FM) is:

$$S/N \text{ (video)} = \frac{C}{No} \quad \frac{12 (\triangle F_S)^2}{bn^3}$$

where

C = carrier power in watts

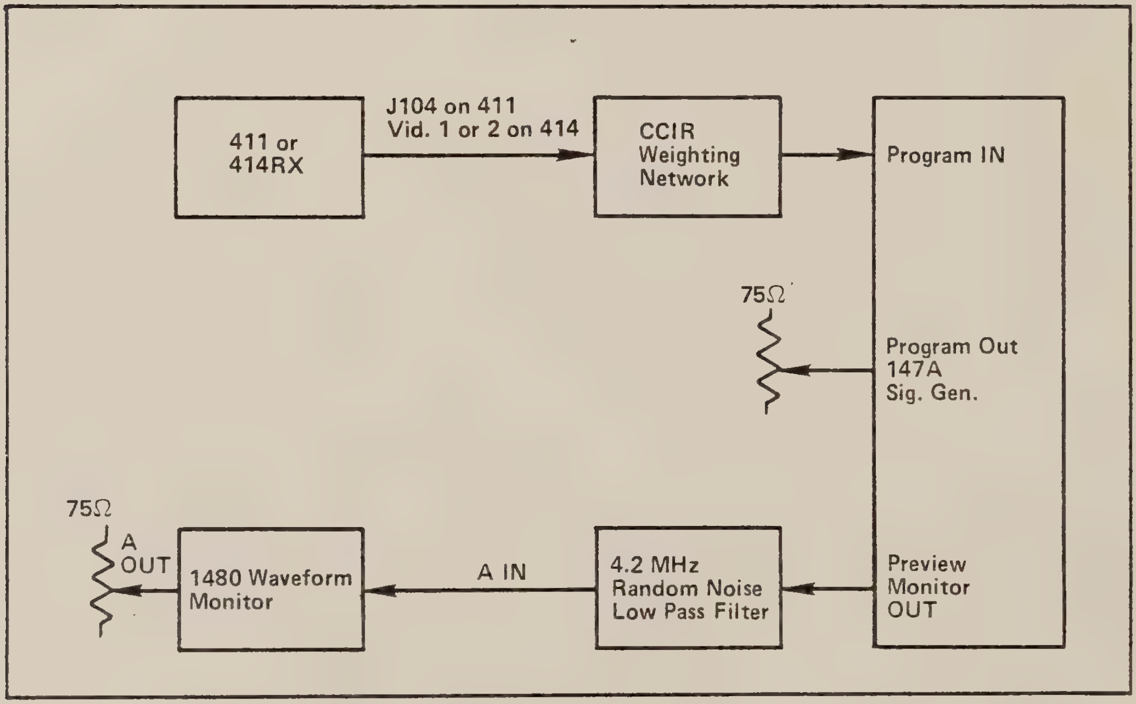
No = noise power density at that point in the system where C is measures

Fs = Half the peak-to-peak deviation caused by that portion of the video waveform defined as the "signal".

bn = Noise bandwidth of the baseband filter function which represents the combination of the de-emphasis network, measurement band-limiting filter, and weighting network with respect to triangular noise.

Examining the parameters which affect video signal-to-noise ratio one can readily see that the uplink operating parameters EIRP, deviation, etc., and the receive station equipment performance-antenna through video amplifiers are verified. The video signal-to-noise ratio (CCIR) is measured as follows:

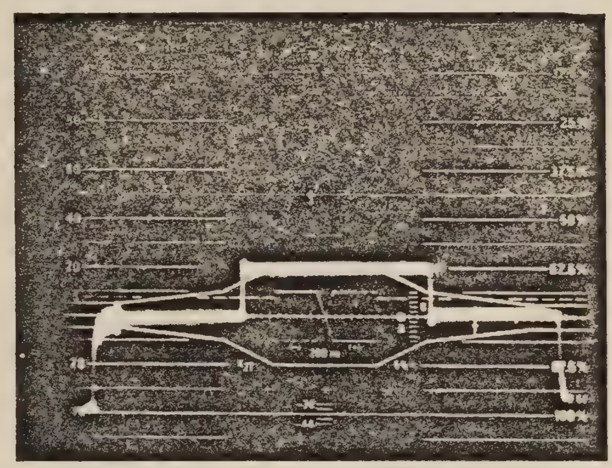
A. Interconnect the receiver and test gear as shown in the block diagram.




B. Set 147A controls as listed below:

| | |
|---|---|
| Function Switch | – Noise |
| Local-Remote | – Local |
| Gain-Variable/Unity | – Unity |
| Program/Preview | – Preview |
| Noise Attenuators | – 40 dB |
| Delete half line/full line | – half line |

C. Program 147A to insert noise on line 17 both fields — see 147A Operation Manual for details.
D. Adjust 1480 waveform monitor to display line 17, field 1.
E. Adjust pedestal height (147A) until the inserted noise is at the same APL as the BAR in the composite test waveform.
F. Adjust the noise attenuators until the inserted noise is the same amplitude as the noise on the BAR.
G. Read and record the S/N ratio from the noise attenuators on the 147A Signal generator.



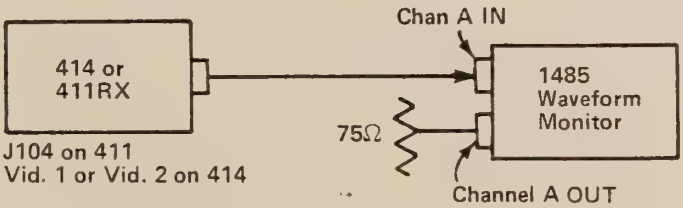
**Waveform Monitor Display Showing Flatfield & Random Noise Test Signal.**

3. Reduced Amplitude Video Response

This test verifies the frequency response of the up and down link video processing circuitry at six discrete frequencies form 0.5 MHz.

A subjective indication of phase response is shown by the degree of distortion or "rounding off" of the discrete frequency bursts. Reduced amplitude video response is measured as follows:

a. Interconnect the receiver and test equipment as shown in the block diagram.

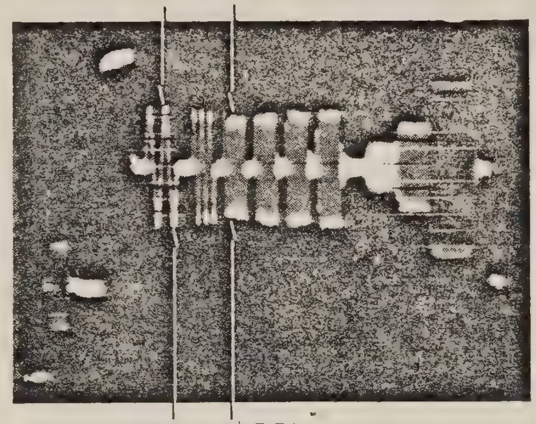



b. Adjust waveform monitor to display the multiburst test waveform (line 17, field 2 on HBO programming).

c. Adjust the "volts per full scale" control and "calibrate" control to a point such that the highest amplitude burst covers the area between 0 and 100 on the display graticule. This sets the amplitude of the higher amplitude burst at 20 "units".
d. Count the number of units covered by the lowest amplitude burst.
e. Reduced amplitude video response in

dB = 20 log highest burst amplitude lowest burst amplitude

EXAMPLE:
highest burst = 20 "units"
lowest burst = 16.5 "units"
reduced amplitude video response = $20 \log \frac{16.5}{20} = 1.67$ dB



20 Div. 16.5 Div.

4. "K" Factor $K_{2t}$

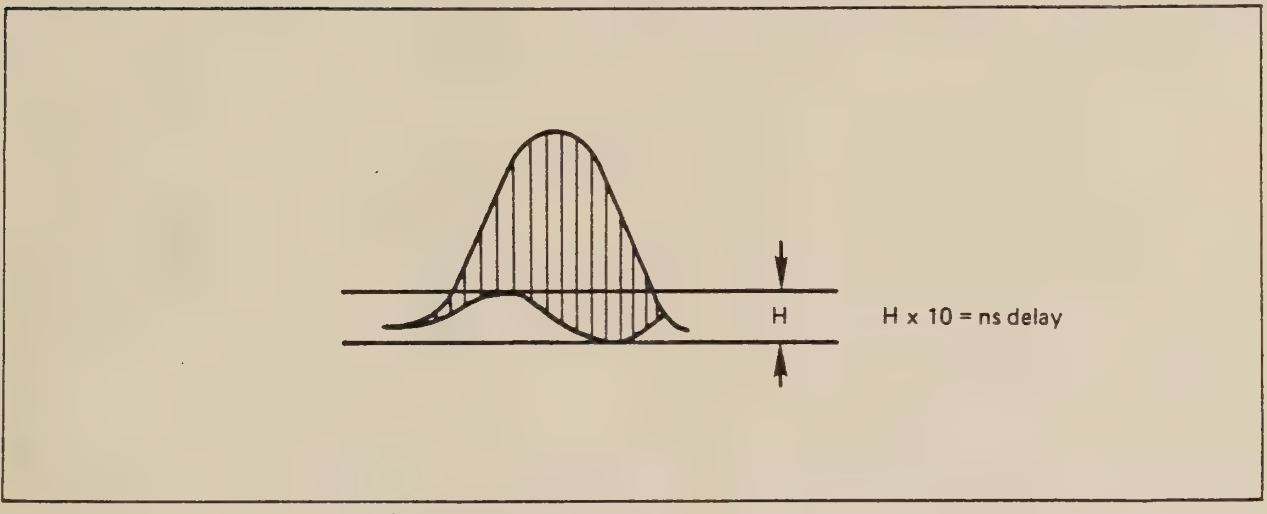
K factor is a measure of the short time response of the up and down link video processing circuitry. This measurement also gives subjective indications of phase and delay distortions as indicated by the distortion of the 2t pulse's height and width. "K" factor is measured as follows:

a. Interconnect receiver and test equipment as shown for reduced amplitude video response.
b. Obtain composite video test waveform on WFM display. Center 2t pulse in the "K" factor window on the display graticule and adjust volts per full scale calibrate control so that the 2t pulse covers the area between the 0 or baseline point to the 100 unit.
c. Set mag. control to X25 and center the 2t pulse in the "K" factor window.
d. When volts per full scale = 1 volt the window is 5%
= 0.5 volt the window is 2.5%
= 0.2 volt the window is 1%
e. Adjust volts per full scale until the ringing after and before the 2T pulse is just contained in the window limits or the 2T pulse reaches the window shape factor limits. Interpolate and record the results as "K" factor ($K_{2T}$).

5. Luminance-Chrominance Delay

Luminance-Chrominance delay is a measure of the systems delay characteristics at chrominance frequencies with respect to luminance frequencies. L/C delay is measured as follows:

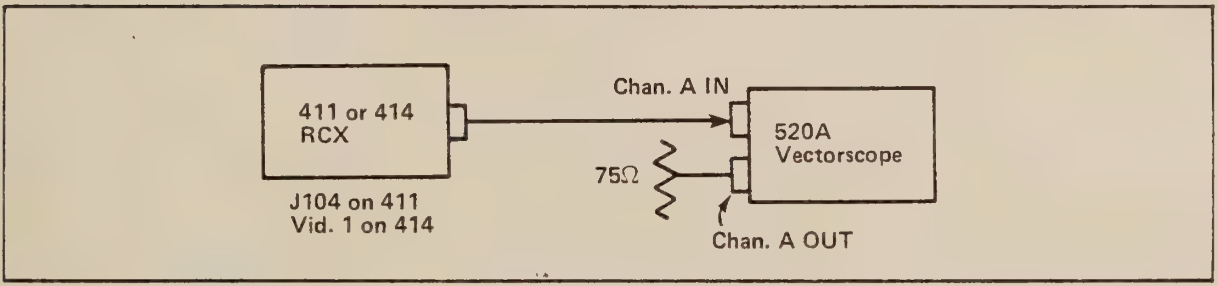
a. Interconnect equipment as shown for reduced amplitude video response.
b. Obtain the composite video test waveform on the waveform monitor display.
c. Adjust mag. control for best resolution of 12.5T modulated sine² pulse.
d. Measure the peak-to-peak amplitude of the sinesouidal base line distortion of the 12.5T pulse in IRE units.
e. For 12.5T pulse delay nsec = 10 x peak-to-peak IRE from above.

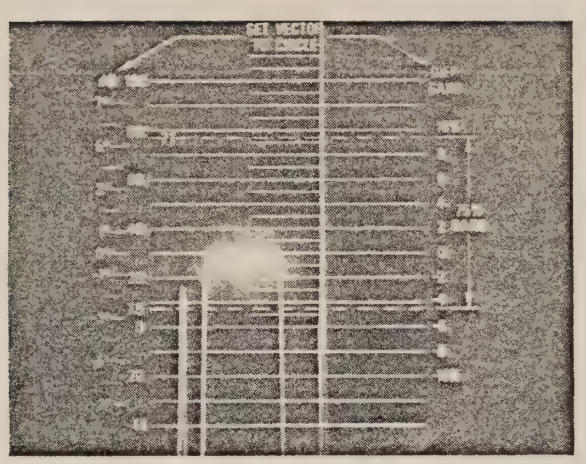



6. Differential Gain

Differential gain is defined as the change in amplitude of the subcarrier portion of the modulated staircase as the luminance portion of the staircase is varied from blanking level to white level. Differential gain's most notable effect is observed as misregistered shade in the color television picture. Differential gain is measured as follows:

a. Interconnect the equipment as shown in the block diagram.





b. Set the vector scope line selector switch for the line number which contains the composite video test signal.
c. Depress the Channel A, vector, and VITS Field 1 or VITS Fiels 2 selectors as appropriate.
d. Adjust channel gain and phase controls until the vectors lie on the 180° line and coincide with the outer circle on the graticule.
e. Depress the differential gain selector and read differential gain in % from the vectorscope graticule.

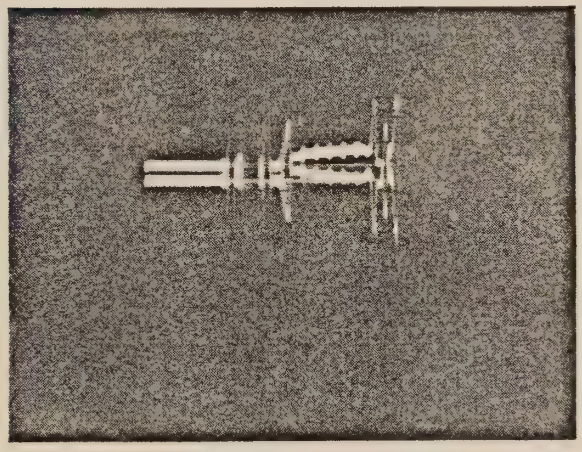
Differential Gain Cal Factor

| | |
|---|---|
| 0.1 dB | 1.2% |
| 0.2 dB | 2.3% |
| 0.3 dB | 3.4% |
| 0.4 dB | 4.5% |
| 0.5 dB | 5.6% |
| 0.6 dB | 6.7% |
| 0.7 dB | 7.8% |
| 0.8 dB | 8.8% |
| 0.9 dB | 9.8% |
| 1.0 dB | 10.9% |
| 1.1 dB | 11.9% |
| 1.2 dB | 12.9% |
| 1.3 dB | 13.9% |
| 1.4 dB | 14.9% |
| 1.5 dB | 15.8% |

7. Differential Phase

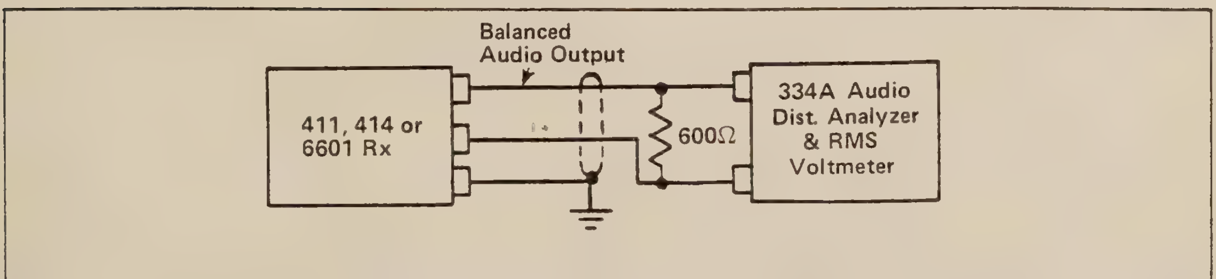
Differential phase is defined as the change in phase of the subcarrier portion of the modulated staircase as the luminance portion of the modulated staircase is varied from blanking level to white level. Differential phase's most notable effect is observed as misregistered hue in the color television picture. Differential phase is measured as follows:

a. Interconnect equipment as shown in the block diagram for differential gain.
b. Set vector scope line selector switch for the line number which contains the composite video test signal.
c. Depress the Channel A, vector, and VITS Field 1 or Field 2 selectors as appropriate.
d. Set calibrated phase to 0°.
e. Adjust channel gain and phase until the vectors lie on the 180° line and coincide with the outer circle on the graticule.
f. Depress differential phase button and adjust the channel phase control until one extremity of the differential phase lines coincide with one another. Adjust the calibrated phase control until the other extremity of the differential phase lines coincide — note the calibrated phase control reading and record as differential phase.



8. Audio Test Tone Signal/Noise

a. Interconnect the quipment as shown in the block diagram.




b. Obtain a 1 kHz audio test tone from the source.
c. Set 334A for RMS voltmeter mode of operation.
d. Obtain 1 kHz audio test tone from source.
e. Set 334A for RMS voltmeter mode of operation. Record signal + noise power from meter. Have the test tone removed and the input terminated at the source. Record the noise power indicated on the meter. The autio signal/noise is the (signal + noise power) — (noise power).

9. Audio Test Tone Distortion.
   a. Interconnect the equipment as shown for audio signal/noise measurement.
   b. Set 334A for distortion analyzer mode of operation.
   c. Obtain 1 kHz audio test tone from source.
   d. Adjust and optimize analyzer notch filter for the lowest % reading on the meter.

**Maintenance** Periodically inspect the receiver mainframe for signs of damage from mechanical abuse. Also, look for evidence of overheating, especially in the power supply. An accumulation of dust on the power supply heat sink will have an insulating effect and prevent efficient heat dissipation. Keep both the inside and the outside of the mainframe clean. A low pressure air hose and a small paint brush can be used to clean connectors. The module edgeboard connectors can be cleaned with an art gum eraser. Spare modules should not be subjected to excessive heat, humidity, or vibration. The antenna feed and coaxial cable pressurization unit should be checked periodically for proper operation. If a "dry air" system is used the desicant should be changed when two thirds of the cylinder shows moisture contamination.

**Fault Isolation** The information provided in this section will aid the operator in locating a faulty module so that he may replace it with a spare and resume operation. These module-level fault-isolation procedures are performed primarily with the receiver's front-panel meter and a volt-ohm meter. IF measurements, when necessary, can be made with a power meter such as the Hewlett/Packard Power Meter Model 435A.

If a spectrum analyzer is available, RF input measurements, as well as more precise IF measurements, can be made. The extender module, which is included in the optional service kit, is not required for module isolation.

The more detailed troubleshooting information in the module sections of the appropriate "Instruction Manual" will permit an experienced technician to further isolate a problem and make repairs. The equipment required for those procedures is listed in the "Instruction Manual."

—CAUTION—

Scientific-Atlanta recommends that, during the warranty period, any malfunctioning module be returned to the factory for repair. Damages sustained during the course of repair efforts may void the warranty.

In the event of an apparent malfunction, the operator should make the following preliminary checks before tracing signals.

a. If the POWER switch does not illuminate, the input fuse may have blown or the ac power line may not be properly connected.
b. Using the front panel meter, or voltmeter, check for the presence of the plus and minus dc supplies.
c. Make sure all modules are firmly inserted in the proper locations.
d. Make sure rear panel connections are complete.
e. Make sure the downconverter frequency determining elements (Switch X'tal, etc.) set to the proper frequency.
f. Check the antenna for proper orientation.
g. Check the level and modulation settings of external equipment connected at the receiver's output. Incorrect settings can cause distortion of the video signal.

If there are other receivers at the site, external problems can be identified by comparing the apparently faulty receiver to one that is operating properly. First set the downconverter thumbwheel switches to a frequency being received by another unit. If the receiver now performs properly, then there must be a problem with the incoming signal at the frequency for which it was previously set.

If, however, the malfunction persists, it will be worthwhile to check the external equipment connected at the output of the suspected receiver against equipment performing satisfactorily with another receiver. With the downconverter switches still set on the frequency known to be operational, connect the good output signal processing equipment to the receiver's output connectors. If the resulting output is still unacceptable, the receiver itself must be at fault.

Most instances of apparent receiver failure, especially those involving a noisy video signal, can be traced to a poor quality uplink signal, improper antenna orientation, or a malfunction in station equipment external to the receiver. These items should be checked very carefully before tests involving the receiver are undertaken.

# BIOGRAPHICAL SKETCH

HOWARD L. CRISPIN

## Education

| | |
|---|---|
| Associates in E. E., Franklin University | 1955 |
| Advanced Studies in Mathematics, Ohio State University | 1956-1957 |
| Program for Management Development, Harvard Graduate School of Business | 1971 |

## Experience

| | |
|---|---|
| **North American Aviation** | |
| Research Engineer | 1955-1958 |
| **Brunswick Corporation** | |
| Manager, Electronics Division | 1958-1963 |
| **Scientific-Atlanta, Inc.** | |
| Marketing Manager, Antenna Instrumentation | 1964-1967 |
| Manager, Western Region | 1967-1968 |
| Manager, Instrumentation Product Line | 1968-1970 |
| Vice President, Marketing | 1970-1971 |
| Vice President, Corporate Development | 1971-1972 |
| Vice President, Marketing | 1972-1976 |
| Senior Vice President, Communications Group | 1976-Present |

## Fields of Special Interest and Experience

Antenna and Microwave Instrumentation
Microwave Component Development
Electromagnetic Windows
Sales and Marketing
General Management

## Papers and Publications

"Filament Winding Radomes and Missile Nose Cones," published in The Glass Industry; January 1961

"Continued Evaluation of the One-Horn Interferometer," published in Proceedings of the Radome Symposium, Ohio State University; 1962

"The Ultrasonic Vidigage as a Production and Quality Control Aid in Reinforced Plastic Manufacturing," published in The Ultrasonic; September 1963

"Millimeter-Wavelength Mixers for Antenna Measurements Receivers," presented at the First Annual Microwave Exposition, June 1967

"The Outlook for Small to Medium Earth Stations & Associated Equipment" Presented at SATCOM '78; May 1978

"Maritime Satellite Communications" - Presented at U.S./Southeast Asia Telecommunications Conference & Exhibition; Singapore 1978

"Satellite Communications & Earth Stations" - Presented at U.S. Dept. of Commerce Technology Sales Seminar - Africa; September 1976

Honors and Professional Affiliations

Member, Institute of Electrical and Electronics Engineers
Member, Microwave Theory and Techniques Group, IEEE
Member, Antennas and Propagation Group, IEEE
Member, American Institute of Aeronautics and Astronautics (AIAA)

# BIOGRAPHICAL SKETCH

## GUY W. BEAKLEY

### Education

| | |
|---|---|
| Vanderbilt University, B.E. | 1964 |
| Yale University, M.S. | 1965 |
| Yale University, M. Phil. | 1968 |
| Yale University, Ph. D. | 1970 |

### Experience

| | |
|---|---|
| DuPont - Summers | 1964 – 1965 |
| Autonetics – Summer | 1966 |
| RCA Laboratories | 1969 – 1977 |
| Head, Image Processing Research | |
| Member of the Technical Staff | |
| Scientific-Atlanta, Inc. | |
| Manager of Engineering, SatCom Division | 1977 – Present |

### Reports and Publications

"Pattern Recognition Using Distribution - Free Tolerance Regions," Dunham Laboratory Control Theory Symposium, Yale University, Dec. 1967, pp. 37-40.

"Application of Distribution - Free Tolerance Regions to Automatic Speaker Verification", J. Acoust. Soc. Am., Vol. 46, No. 1, July 1969, p. 90(A). An expanded version was presented at the Second Annual Dunham Laboratory Control Theory Symposium, Yale University, New Haven, Conn., March 1969.

"Comments on 'A Nonparametric Partitioning Procedure for Pattern Classification'," IEEE Trans. on Computers, April, 1970, pp. 362-363.

"A System for the Automatic Recognition of Speech Received Via the Telephone," RCA Technical Report, February 1971.

"Equipment Modification for Collecting Speech Amplitude Data for Computer Processing.., RCA Technical Report September 1971.

"High Accuracy Recognition of Speech Received Via the Telephone," Workshop on Automatic Pattern Recognition Problems in Speech," RADC, Rome, NY, September 1971.

"Optimizing the Unvoiced-Voiced Decision for Speech Received Over the Telephone Network", RCA Technical Report, March 1972.

"Reliability of a Communication System for the Alaskan Pipeline," RCA Technical Report, August 1972.

"Distribution-Free Pattern Verification Using Statistically Equivalent Blocks," IEEE Trans. on Computers, Vol. C-21, No. 12, Dec. 1972, pp. 1337-1347. (coauthor)

"Text for Department of Interior Briefing on the Reliability of the Pipeline Communication System," RCA Technical Report, April, 1971.

"Color TV Receiver Accelerated Life Test," RCA Technical Report, August 1974. (coauthor)

"A Model of Product Quality at the Bloomington Color TV Plant," RCA Technical Report, March 1975. (coauthor)

"Television by Satellite Experiment Conducted at Scientific-Atlanta," RCA Technical Report, May 1975. (coauthor)

"Performance of Frequency Modulation Systems for Transmitting TV to Small Earth Stations," RCA Technical Report, May 1975.

"Evaluation of Schemes for Television Transmission to Small Earth Stations," RCA Technical Report, September 1975. (coauthor)

"Television to the Alaskan Bush," RCA Technical Report, Feb. 1976.

"Two Television Channels Per Transponder in Satellite Communications," RCA Technical Report, March 1976.

"Testing of Television Earth Station Receivers," RCA Technical Report, June 1976. (coauthor)

"Television to Small Earth Stations", IEEE Trans. on Broadcasting, BC-22, No. 3, September 1976. Also presented at the ICC, Philadelphia, Pennsylvania, June 1976.

"Testing of Television Earth Station Receivers for the Alaskan Bush", RCA Technical Report, November 1976. (coauthor)

"Television Parameters for Alaskan Satellite Service", paper presented at Electro '77, New York, New York, April 20, 1977.

"Technology and Parameter Trade-Offs in Ratio Distribution by Satellite", presented at engineering and management workshops, National Association of Broadcasters, Las Vegas, Nevada, April 9-12, 1978.

"Interference Effects in Small Satellite Receive Terminals", NTC '78, Birmingham, Alabama, December 4-6, 1978. (coauthor)

"A System Design for Satellite Communications to the Australian Outback", Pacific Telecommunications Conference, Honolulu, Hawaii, January 7-8, 1979. (coauthor)

## BIOGRAPHICAL SKETCH

## FREDERICK M. FONDA, JR.

### Education

| | |
|---|---|
| United States Naval Academy | 1947 – 1951 |
| University of California | 1958 |

### Experience

| | |
|---|---|
| Westinghouse Electric Corporation | |
| Engineer | 1951 – 1956 |
| Sylvania Electronic Systems | |
| Engineering Specialist | 1956 – 1965 |
| Plastic Structures, Inc. | |
| Vice President, Engineering | 1965 – 1969 |
| Prodelin Pacific, Inc. | |
| Division Vice President | 1969 – 1972 |
| Scientific-Atlanta, Inc. | |
| Manager, Structures Engineering | 1972 – Present |

### Fields of Special Interest and Experience

Lightweight Shipboard Antenna Pedestal Control Systems
Lightweight Composite Material Structures
Antenna Structures and Positioning Systems

### Papers and Publications

"Wind-Induced Moments of a Concave and a Biconvex Parabolic Reflector," Sylvania Electric Products, Inc., Internal Memorandum EDL-S310, June 1965.

"Shipboard 3-Axis Antenna Pedestal System," Funded study published at Plastic Structures, Inc., Santa Clara, California, for Philco W.D.C., Palo Alto, California, 1967

"Fiberglass Pedestal," Funded study for U.S. Army Signal Corps done at Sylvania E.D.C., Mt. View, California, 1965.

### Patents

"Antenna Drive System," Patent No. 3,372,603.

# BIOGRAPHICAL SKETCH

## SHARAD V. PAREKH

### Education

| | |
|---|---|
| Oxford College of Technology, Oxford, U.K. | 1962 |
| University of Leeds, Leeds, U.K. | |
| B. Sc. Electronic Engineering | 1965 |
| Philips Institute, Eindhoven, Holland | |
| M. Sc. Electronic Engineering | 1967 |
| University of Leeds, Leeds, U.K. | 1970 |
| Queen Mary College, University of London, U.K. | |
| Ph. D. Microwave Engineering | 1970 |

### Experience

| | |
|---|---|
| Philips Development Labs, Eindhoven, Holland | |
| Engineer, Study of arc extinction phenomenon in ignitrons | 1964 |
| Philips Research Labs, Eindhoven, Holland | |
| Research Engineer, Study of linear and non-linear properties of ferrites at microwave frequencies | 1966 – 1967 |
| University of London, London, U.K. | |
| Research Assistant, Inhomogeneous loaded waveguide radiator research | 1967 – 1970 |
| Standard Telecommunication Labs., Ltd., Harlow, Essex, U.K. | |
| Research Engineer, Antenna Division | 1970 – 1973 |
| Scientific-Atlanta, Inc. | |
| Senior Antenna Engineer, Electro-Systems Division | 1974 – Present |

### Fields of Special Interest and Experience

Antenna Design and Analysis
Microwave Components
Satellite Communications Systems
Telecommunication Systems
Tracking Systems

Papers and Publications

"Measurement of Ferromagnetic Resonance of Ni-Zn Ferrites at Microwave Frequencies", Thesis, 1967

"Theory and Design of Multiple-Beam Leaky-Wave Antennas", Thesis, 1970

"On the Ferromagnetic Resonance of Spherical Ferrite Samples", Int. J. Electronics, June, 1971

"The Mode-Matching Method as Applied to Ridged Waveguides", Int. J. Electronics, June, 1972

"Radiation of Coupled Waveguides Antennas", Proc. IEE, September, 1972

"The Eigenvalue Solution of Asymmetric-Ridge Waveguides Using the Mode-Matching Method", Int. J. Electronics, September, 1973

"Multipath Effects of Dry and Wet Radomes on Parabolic Reflector Antennas", Scientific-Atlanta Report 74-45-11, April, 1975

"Comments on Loss in Gain Due to Feed Support Blockage", Scientific-Atlanta Report 75-45-14, July, 1975

"An Independent Polarization Rotatable 4- and 6-GHz Feed for Application in a Frequency Reuse System", Scientific-Atlanta Report 75-45-18, December, 1975

"Antenna Noise Temperature Analysis Based on Radiation Pattern Characteristics", Scientific-Atlanta Report 75-45-15, March, 1976

"A Note on the Aperture Distribution of Cassegrain Antennas", Scientific-Atlanta Report 76-45-32, August, 1976

"Performance Improvement in 4- and 6-GHz Polarization Rotatable Feed", Scientific-Atlanta Report 76-45-28, June, 1976

"Depolarization Effects Due to Rain and Faraday Rotation in the Frequency Reuse System", Scientific-Atlanta Conference on Earth Station Technology, Atlanta, July, 1976

"Impedance Matching of Corrugated Horns", Scientific-Atlanta Report 77-45-37, March, 1977

"Reshaped Subreflectors Reduce Antenna Sidelobes , Microwaves", May, 1977

"Comments on 'Analysis of an XPD Event'," Forwarded to Proceedings IEEE, April, 1977

"Frequency Reuse — Cross-Polarization Discrimination and Feed Components", Scientific-Atlanta Seminar on Earth Station Technology, Atlanta, June, 1977

"Gain Measurement Errors Resulting from Use of Non-Ideal Sources," Microwaves, November 1978

Patents

"Endfire Commutated Reference Array for Doppler Landing System", Patent 3883875

## BIOGRAPHICAL SKETCH

## JAMES A. HART, JR.

### Education

| | |
|---|---|
| B.E.E., Georgia Institute of Technology | 1962 |
| M.S.E.E., Georgia Institute of Technology | 1966 |

### Experience

| | |
|---|---|
| Sperry Microwave Electronics Company | |
| Engineer | 1962 – 1964 |
| Georgia Institute of Technology Engr. Exp. Station | |
| Assistant Research Engineer | 1964 – 1966 |
| Scientific-Atlanta, Inc. | |
| Senior Engineer | 1966 – 1975 |
| Staff Engineer | 1975 – Present |

### Papers and Publications

"Study of Pulsed Radiation Effects on Microwave Ferrite Duplexers"

Quarterly Reports, Contract No. DA36-039-SC-89113, Sperry Microwave Electronics Company, 1963 (coauthor)

"Communications Receivers Interference Reduction Mods," Technical Report No. RADC-TR-65-97, June 1965 (coauthor)

"UHF Active Cancellation Filter," Technical Report No. RADC-TR-66-10, May 1966

"Full Power Testing of Sonar Transducers," Under Sea Technology, May 1969

"Satellite Receive System," Earth Terminal Technology Conference, July 14-16, 1976, Atlanta, Georgia

"CATV Earth Station Reliability," 2nd Annual NCTA/IEEE Reliability Conference, 1977, Atlanta, Georgia (coauthor)

"Comparison of Performance Criteria of Five and Ten Meter Earth Terminals," NCTA 1977, Chicago, Illinois

### Fields of Special Interest and Experience

Network and Circuit Design
Underwater Sound Propagation
Communications Systems and Component Design
CATV Systems and Component Design
Satellite Communications Systems

### Registrations

Member, Institute of Electrical and Electronics Engineers
Professional Engineer, Georgia, No. 8035

# BIOGRAPHICAL SKETCH

## PATRICK H. NETTLES

**Education**

| | |
|---|---|
| B.S. in Physics, Georgia Institute of Technology | 1964 |
| Ph. D. in Physics, California Institute of Technology | 1970 |

**Experience**

| | |
|---|---|
| University of North Carolina at Chapel Hill and Triangle Universities Nuclear Laboratory | |
| Instructor and Member of Research Staff | 1970 – 1972 |
| Scientific-Atlanta, Incorporated | |
| Senior Physicist | 1972 – 1976 |
| Staff Physicist | 1976 – 1977 |
| Manager, SCPC Engineering | 1977 – 1978 |

**Publications**

Several in the field of experimental nuclear physics.

**Other Contributions**

Panel Member, NCTA Show, 1973 (Anaheim) "The Elusive Subscriber Service Terminal"

Forum Member, National Security Conference, 1974 (Los Angeles) "CATV Security Systems"

Member, IEEE Communications Society

COMSAC Space Communications Committee

# BIOGRAPHICAL SKETCH

## H. MICHAEL SMITH

**Education**

| | |
|---|---|
| BSEE, University of Florida | 1966 |

**Experience**

| | |
|---|---|
| Boeing Company, Kennedy Space Center | |
| Test Engineer | 1966 – 1969 |
| Tampa Electric Company, Electric Utility | |
| Electrical Engineer | 1969 – 1972 |
| General Electric Cablevision Corporation | |
| Engineering Manager | 1972 – 1977 |
| Scientific-Atlanta, Inc. | |
| Sales Manager, Earth Stations | 1977 – Present |

**Honors and Professional Affiliation**

Member SCTE

**Registrations**

Professional Engineer, State of Florida, No. 11891

**Technical Papers and Publications**

"Utility Grounding Practices" Cablecasting Magazine July/August 1973

## BIOGRAPHICAL SKETCH

### RAY STUART

**Education**

| | |
|---|---|
| BSEE, Mississippi State University | 1970 |
| Graduate Work, MSU/VPI | 1970 – 1975 |

**Experience**

| | |
|---|---|
| Ford Aerospace | |
| Principal Engineer | 1961 – 1973 |
| U.S. Government | |
| DCA/U.S. Army Civilian | 1973 – 1975 |
| Ford Aerospace WDL Division | |
| Manager, System Engineering Department (STO) | 1975 – 1978 |
| Scientific-Atlanta, Inc. | 1978 – Present |

# BIOGRAPHICAL SKETCH

## FRED A. SMITH

| | |
|---|---|
| **Education** | |
| Florida Institute of Technology, Melbourne, Florida | 1967 – 1968 |
| Jacksonville University, Jacksonville, Florida | 1968 – 1969 |
| Florida Institute of Technology, Melbourne, Florida | 1969 – 1972 |
| **Experience** | |
| Florida Institute of Technology | |
| Electronic Technician | 1970 – 1972 |
| Electronic Systems Division of Harris Corporation | |
| Electrical Engineer | 1972 – 2973 |
| Jackson & Church Electronics | |
| Electrical Engineer | 1973 – 1974 |
| Electronic Systems Division of Harris Corporation | |
| Senior Electrical Engineer | 1974 – 1975 |
| E-A Industrial Corporation | |
| Senior Reliability Engineer | 1975 – 1976 |
| Scientific-Atlanta, Inc. | |
| Quality Assurance Engineer | 1976 – Present |

## BIOGRAPHICAL SKETCH

## MARVIN D. SHOEMAKE

**Education**

| | |
|---|---|
| B.E.E. Southern Technical Institute | 1972 |

**Experience**

Scientific-Atlanta, Inc.

| | |
|---|---|
| Engineering Technician | 1967 – 1970 |
| Associate Engineer | 1970 – 1972 |
| Engineer | 1972 – 1975 |
| Senior Engineer | 1975 – 1976 |
| Supervisor, Product Line Operations | 1976 – 1977 |
| Manager, Antenna Products | 1977 – 1978 |
| Product Line Manager, Satellite Communications Antenna Products | 1978 – Present |

**Fields of Special Interest and Experience**

Microwave Component Design
Antenna Feed Designs
Log Periodic Antenna Designs
Design and Development of Terrestrial Microwave Communication Antennas
Tracking Antenna Designs — VHF, L-, S-, C-, X-, and Ku-Band Systems
Design and Development C-Band Stripline Monopulse Comparator
Multi-Element Log Periodic Array Design
Multi-Band Surveillance System Design
Tracking System RF and Link Analysis
Developed Computer Programs for Analyzing Noise Temperature of High Gain Antennas
Computer Design of Cassegrain Antennas
Computer Aided Prediction for Maximum Return Loss of Multi-Wavelength Line with Discrete Components
Design and Development of MARISAT Multi-Band Satellite Test Antenna
Development of Satellite Earth Station Antennas
Design and Development of 4- and 6-GHz Wide Flare Angle Multi-Mode Feed

**Papers and Publications**

"Antenna Noise Temperature Analysis," 1975

"Path Considerations and Effects to Received Signal Levels at the Ground Station," 1976

"Earth Station Antenna Considerations," 1976

"The Small Antenna for Satellite Communications," 1977

**Honors and Professional Affiliations**

Institute of Electrical and Electronics Engineers
Antennas and Propagation
Microwave Theory and Techniques

## BIOGRAPHICAL SKETCH

## THOMAS M. WILLIAMS

| | |
|---|---|
| **Education** | |
| B.S. in E.E., Georgia Tech | 1967 |
| Graduate School Florida Tech | 1967 – 1968 |
| Graduate School Georgia Tech | 1974 – 1975 |
| **Experience** | |
| Radiation, Inc. | |
| Engineer | 1967 – 1968 |
| Scientific-Atlanta, Inc. | |
| Engineer | 1968 – 1971 |
| Integrated Systems | |
| Engineer | 1971 – 1973 |
| Western Electric Company | |
| Planning Engineer | 1973 – 1975 |
| Scientific-Atlanta, Inc. | |
| Senior Engineer | 1975 – Present |

**Honors and Professional Affiliation**

IEEE
Society of Broadcast Engineers
Tau Beta PI – Engineering Honorary
Eta Kappa – E.E. Honorary

**FCC License**

First Class Radiotelephone
Amateur Advanced Class

CHARLES DANIEL YOST
Vice President

Mr. Yost is Manager of Earth Satellite and Land Mobile Services for Compucon. He is responsible for systems design, earth satellite coordination, land mobile system design, and computer systems development for Compucon.

He received a B.S. degree in electrical engineering from Southern Methodist University in Dallas, and a M.B.A. from the SMU graduate school. He is a member of The Institute of Electrical and Electronics Engineers (IEEE), Sigma Tau (Honorary Engineering Fraternity), and Eta Kappa Nu (Honorary Electrical Engineering Fraternity).

Mr. Yost has been Project Manager of earth station placement and coordination projects for RCA Globcom, RCA Alascom, GE, Federation of Rocky Mountain States, United Video, ITT, and IBM and has been a project engineer on similar projects for Hughes Communications and TeleCommunications, Inc. Mr. Yost has recently been responsible for the placement of earth stations for the Broadcast and Cable TV Industries.

BIOGRAPHICAL SKETCH

HARRY L. STEMPLE, III
Registered Professional Engineer

Education
- West Virginia University, BSEE
- Syracuse University, Communications
- George Washington University, Computer Science

Experience

ATLANTIC RESEARCH CORPORATION 1964 – 1969
- RFI measurements for military systems
- Studies of communication degradation in the presence of interference
- Design of interference analysis and frequency assignment program for microwave systems.

SPECTRUM ANALYSIS AND FREQUENCY ENGINEERING 1969 – 1977
- Vice President and Operations Manager Interference analysis for microwave systems.
- Satellite earth station coordination
- Frequency coordination systems analysis

COMSEARCH, INC. Present
- President
- Frequency coordination for satellite earth stations and terrestrial microwave facilities.
- Development of frequency coordination computer programs.

## BIOGRAPHICAL SKETCH

### JAMES H. COOK, JR.

**Education**

| | |
|---|---|
| B.E.E., Georgia Institute of Technology | 1961 |
| M.S., E.E., Georgia Institute of Technology | 1970 |

**Experience**

| | |
|---|---|
| Bendix Radio, Division of the Bendix Corporation | |
| Junior Engineer | 1961 – 1964 |
| Scientific-Atlanta, Inc. | |
| Microwave Engineer | 1964 – 1968 |
| Senior Engineer | |
| Manager, Antenna & Microwave Products | 1968 – 1972 |
| Product Line Manager, Telecommunication Products | 1973 – Present |

**Papers and Publications**

| | |
|---|---|
| Microvision-Ground Antenna Study Report (Co-author) | 1963 |
| Pulse Spectrum Analysis by Fourier Methods | 1963 |
| A Slotted Waveguide Array Design | 1964 |
| Nine classified reports on "Adaptive Signal Processing Array Techniques" (Co-author) | 1963 – 1964 |
| Classified report on "Pulse Compression Analysis for FPS-85 (SPADATS) Improvement Program" (Co-author) | 1964 |
| Microwave 5 to 1 Bandwidth 3 dB Directional Coupler | 1964 |
| The Theoretical and Measured Characteristics of the Diagonal Horn Antenna | 1968 |
| "Antenna Pattern Measurements," Chapter 6, Microwave Antenna Measurements, J.S. Hollis, et al, Scientific-Atlanta, Inc., (Co-author) | 1969 |

**Honors and Professional Affiliations**

Institute of Electrical and Electronic Engineers
Microwave Theory and Techniques Group
Antennas and Propagation Group

# BIOGRAPHICAL SKETCH

## BARRY R. SHARP

**Education**

Georgia Institute of Technology
B.E.E. Cooperative Plan — 1971 – 1976

**Experience**

Scientific-Atlanta, Inc.
Engineer — 1976 – Present

**Honors and Professional Affiliations**

Eta Kappa Nu
Phi Kappa Phi
Tau Beta Pi

**Fields of Special Interest & Experience**

Digital Logic
Video Alarm Circuitry
Power Supplies
Switching Power Supplies